Vol. XIII, Part I February, 1943



# THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE

Issued under the authority
of
The Imperial Council of Agricultural Research



Annual subscription
Rs. 15 or 23*s*. 6*d*.

Price per part
Rs. 3 or 5*s*.

PUBLISHED BY THE MANAGER OF PUBLICATIONS, DELHI
PRINTED BY THE MANAGER, GOVERNMENT OF INDIA PRESS, NEW DELHI
1943

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600.

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References to literature, arranged alphabetically according to authors' names, should be placed at the end of the article, the various references to each author being arranged chronologically. Each reference should contain the name of the author (with initials), the year of publication, title of the article, the abbreviated title of the publication, volume and page. In the text, the reference should be indicated by the author's name, followed by the year of publication enclosed in brackets; when the author's name occurs in the text, the year of publication only need be given in brackets. If reference is made to several articles published by one author in a single year, these should be numbered in sequence and the number quoted after year both in the text and in the collected references.

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VOLUME XIII, PART I

**(February 1943)**

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# ORIGINAL ARTICLES

## THE COTTON BOLLWORMS (*EARIAS FABIA* STOLL., *PLATYEDRA GOSSYPIELLA* SAUND. AND *HELIOTHIS OBSOLETA* FABR.) IN THE CENTRAL PROVINCES AND BERAR*

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(Received for publication on 14 August 1939)

It was observed by the Entomological Section, Central Provinces Department of Agriculture, that considerable damage was done to cotton by the boll-worms but on account of paucity of staff it was not possible to undertake any detailed investigation on these pests. The sporadic attempts to study the problem and occasional observations made on the subject departmentally did not furnish sufficient data on which to base definite conclusions. A specific scheme for investigation into the bollworm problem was, therefore, started with the funds provided by the Indian Central Cotton Committee. The scheme commenced in July 1934 and terminated in September 1937. The junior author who had worked in the Broach Clean-up Scheme was appointed as Assistant and the work was carried out under the supervision and guidance of the senior author.

The final report of the scheme was submitted to the Indian Central Cotton Committee in May 1938 and the Committee recommended its publication subject to unimportant portions being deleted. This work of deletion was done by the junior author.

The paper, however, still required considerable revision and redrafting which have been carried out by Mr K. R. Sontakay, the present Entomologist to Government, Central Provinces and Berar.

The financial help given by the Indian Central Cotton Committee is gratefully acknowledged.

*Final Report of the Central Provinces and Berar Entomological Scheme financed by the Indian Central Cotton Committee 1934-37

The pink bollworm (*Platyedra gossypiella* Saund.) and the spotted bollworm (*Earias fabia* Stoll.) were known as serious pests of cotton in the Central Provinces and Berar as in other cotton areas of the country, but as no detailed work on them was done the 'Central Provinces and Berar Entomological Scheme' was sanctioned with the object of ascertaining the distribution of the bollworms in the province, their incidence, extent of damage and the means of 'carry-over' from one season to another. Further, the Indian Central Cotton Committee desired that investigation should be undertaken to explore the possibility of applying the results of researches of the Surat Bollworm Scheme to the problem relating to this province. Nagpur was selected as centre for work in the Central Provinces and Akola in Berar.

During the course of investigation it was observed that a third bollworm, i.e. *Heliothis obsoleta*, commonly known as the American bollworm of cotton was also responsible for some damage during the early part of the cotton season. During the final year of the scheme work was mainly concentrated on this insect. The results of investigations are embodied in this paper.

## Soil and climate of the cotton tract

### *Soil*

The soil of the cotton tract of the province is typically clayey loam. It is deep black in colour, subject to waterlogging during continuous heavy rains. Cracks begin to appear soon after the monsoon and these gradually widen till in summer they are as deep as 30 inches.

### *Rainfall and humidity*

Monsoon breaks in the second or third week of June and during July and August the rainfall is heavy. The annual rainfall varies from 28 in. to 32 in. in Berar and from 35 in. to 45 in. in the cotton tract of the Central Provinces. After the rainy season, humidity begins to fall gradually. In the month of May the air becomes very dry and the percentage of moisture is as low as 19 (Appendix I).

### *Temperature*

The climate of the cotton tract is, on the whole, hot and dry with a mild winter. The minimum temperature rarely goes below 56°F. during December and January. From February, the temperature rises and in May, which is the hottest month of the year, it varies between 110°F. and 115°F. and sometimes goes to 118°F. During the monsoon the mean temperature varies in the neighbourhood of 80°F.

## The life of cotton crop in the Central Provinces and Berar

Seed is sown generally in the last week of June or the first week of July after a few heavy showers of rain. The bolls burst in the latter half of October or in early November. Usually pickings are carried out till the end of December but if the rainy season is a prolonged one they are continued till the end of January. The life of the cotton crop in the Central Provinces and Berar covers a period of about 26 weeks from the time of sowing to the last picking.

The cotton grown in this province belongs to the '*neglectum*' group and is mixed with Buri (American cotton) to a certain extent. There is little or no monopodial growth in these types of cotton.

## Incidence of bollworms

Observations carried over three successive seasons, 1934-37, indicate that three types of bollworms, viz. the spotted bollworm (*Earias fabia* Stoll.), the pink bollworm (*Platyedra gossypiella* Saund.) and the American bollworm (*Heliothis obsoleta* Fabr.) cause considerable damage to the cotton crop in this province.

In order to determine the incidence of the bollworms all the reproductive forms from a fixed number of plants were picked and examined. The number of different bollworms found and of the forms damaged by them was recorded.

### Table I

*Bollworm population in cotton seedlings 3 in.-18 in. high*

| Locality | Month and year of examination | Variety | Number of seedlings examined | Number of species of larvae found | |
|---|---|---|---|---|---|
| | | | | *E. fabia* | *H. obsoleta* |
| Akola | July 1935 | Verum | 500 | 2 | 0 |
| | | Buri | 500 | 7 | 4 |
| | August ,, | Verum | 12758 | 11 | 0 |
| | | Buri | 3231 | 13 | 7 |
| | June 1936 | Verum | 271 | 0 | 0 |
| | July ,, | Verum | 2973 | 5 | 0 |
| | | Buri | 868 | 0 | 0 |
| | July 1937 | Buri | 2400 | 17 | 0 |
| | | Verum | 2800 | 6 | 0 |
| | | L. Verum | 1000 | 1 | 0 |
| | August ,, | Verum | 800 | 1 | 0 |
| Nagpur | July 1936 | L. Verum | 27274 | 21 | 0 |
| | August ,, | L. Verum | 59955 | 44 | 0 |
| | July 1937 | Verum. | 4546 | 2 | 0 |
| | | Buri | 397 | 0 | 0 |
| | August ,, | Verum | 2708 | 8 | 0 |
| | | Buri | 1413 | 20 | 0 |
| | | Roseum | 1200 | 14 | 0 |
| | | L. Verum | 1000 | 1 | 0 |

It will be seen from the above table that the spotted bollworm appears in July and does a little damage to seedlings. It is the Buri variety which suffers more than others. In the seedling stage infestation by *H. obsoleta* is practically negligible.

Though the spotted bollworm appears on the cotton crop in the last week of July its progress is retarded due to heavy rains during August and September. From October, it multiplies rapidly and remains active till the end of the season. Thus there is coincidence of the increased bollworm population with the boll formation and consequently the damage is very great (Appendix II).

The pink bollworm makes its appearance on the crop in the latter half of September and gradually increases in number during the next two months. In December it multiplies rapidly till in January almost every boll is infested

by it. *Heliothis obsoleta* makes its appearance on the cotton crop at Akola in the last week of July in small numbers. The attack starts on exotic varieties. The pest gradually multiplies and is at its maximum from the beginning of September to the middle of October. At this time *tur* (*Cajanus indicus*) begins to bear pods and this crop being more favoured the insect moves on to it. *Tur* is commonly grown in the neighbourhood of cotton fields and sometimes in the same field in between eight to ten rows of cotton.

### Nature and extent of damage by the bollworms

The spotted bollworm is found in the tender shoots during the last week of July when the plants are 6-9 in. in height. The larvae bore into the shoots which droop down and wither. The growth of the plants which are bored to a depth of 3-4 in. is arrested, whereas those bored to a depth one or two inches continue to grow as the development of the axillary buds is stimulated. The damage to the top shoots is one per cent and consequently the crop does not suffer any appreciable loss at this stage. Thinning of cotton during July removes some of the larvae but this is hardly an effective check as the operation is done irregularly. The larva immediately after emergence from the egg does not directly feed on the nearest available food but wanders about and then bores in the tender shoot, bud or boll. With the development of buds and bolls the damage is restricted to these forms only. The larva even before it is full grown moves on to other buds or bolls and causes similar damage. In this way it damages many more forms than are actually needed for its full growth.

During the early stage of the crop the larvae of *Heliothis obsoleta* feed on the tender shoots and leaves, but with the development of buds and bolls these are preferred. The caterpillar is a voracious feeder and is capable of finishing a boll of the size of or even bigger than an areca nut in a day. The larva thrusts its head inside the bud or boll and feeds on the entire inner contents. Tender bolls are preferred to older ones.

During the year 1935-36, a group of 500 plants was reserved at Akola to study the problem of bud and boll shedding due to bollworms and to determine the proportion of forms shed due to insect damage to total forms borne by the plants. Daily examination of the shed forms was carried out from the beginning of September till the end of January. The shed material consisted of 2220 buds, 2354 small bolls, 331 medium bolls, 135 big bolls and 125 open bolls. The percentage of damage caused by the three bollworms is given in Table II.

Table II

*Percentage of forms shed due to different bollworms*

| Shed due to | Buds | Small bolls | Medium bolls | Big bolls | Open bolls |
|---|---|---|---|---|---|
| Spotted bollworm . . | 17·0 | 22·7 | 30·8 | 44·4 | 46·7 |
| Pink bollworm . . | 0·5 | 0·7 | 4·0 | 10·0 | 10·0 |
| American bollworm . . | 33·4 | 14·0 | 15·0 | 5·2 | .. |
| Other causes . . . | 49·1 | 62·6 | 50·2 | 40·4 | 43·3 |

The big-sized bolls attacked by bollworms which do not drop open prematurely. One or two locks of such bolls are partly or completely damaged. To estimate the amount of damage, *kapas* (seed cotton) from ¼ acre at Akola Farm and ½ acre at Nagpur Farm was examined during 1935-36 (Table III).

TABLE III

*Percentage of damaged* kapas *in* kapas *of different pickings*

| Date of picking | Percentage of undamaged *kapas* | Percentage of *kapas* partly damaged by | | | Percentage of *kapas* completely damaged by | | |
|---|---|---|---|---|---|---|---|
| | | S.B.W. | P.B.W. | O.C. | S.B.W. | P.B.W. | O.C. |
| | | *Akola* | | | | | |
| 4 Nov. 1935 . | 89·70 | 4·00 | 1·40 | 2·20 | 1·90 | 0·60 | 0·03 |
| 15 ,, ,, . | 85·60 | 7·60 | 2·00 | 2·40 | 1·90 | 0·40 | 0·02 |
| 29 ,, ,, . | 62·70 | 30·10 | 2·20 | 1·40 | 3·60 | 0·02 | 0·01 |
| 20 Dec. ,, . | 61·10 | 20·10 | 6·60 | 2·70 | 6·80 | 1·40 | 1·20 |
| 15 Jan. 1936 . | 52·90 | 22·70 | 7·66 | 5·77 | 8·10 | 1·30 | 1·45 |
| On the whole . | 73·40 | 16·00 | 3·20 | 2·40 | 3·70 | 0·60 | 0·50 |
| | | *Nagpur* | | | | | |
| 5 Nov. 1935 . . | 91·90 | 1·10 | 0·60 | 1·70 | 2·10 | 0·80 | 2·20 |
| 18 ,, ,, . | 93·19 | 0·85 | 0·25 | 0·80 | 2·80 | 0·27 | 1·05 |
| 5 Dec. ,, . | 95·70 | 1·70 | 0·10 | 0·20 | 1·70 | 0·10 | 0·40 |
| 2 Jan. 1936 . | 91·10 | 3·10 | 0·13 | 0·44 | 2·50 | 0·30 | 2·30 |
| On the whole . | 93·80 | 1·60 | 0·23 | 0·66 | 2·30 | 0·20 | 1·20 |

S.B.W. = Spotted bollworm ; P.B.W. = Pink bollworm ; O.C. = Other causes

## LIFE-CYCLE

### *Spotted bollworm*

The life-history and habits of the spotted bollworm in this province are more or less the same as in other cotton tracts of India. The incubation period varies from three to five days depending on the season, shorter time being required during summer. Larval stage lasts from 15 to 18 days during December and January and 10 to 14 days during other months. Pupation takes place generally in the soil either in cracks or under clods. During May 1936, 3641 empty cocoons of the spotted bollworm were recovered from cracks

over an area of half an acre. Some cocoons weie found as deep as 20 inches. The pupal period is about 16 days during winter and about nine days during the rest of the year. The maximum duration of the life of the adult is 36 days in captivity. Experiments conducted to study the egg-laying capacity of the moths showed that the maximum number of eggs laid by a female was 592 and this number was laid in 23 days. The period when most egg-laying occurred was November to February when generally over 300 eggs were laid by a female. The insect does not hibernate or aestivate but breeds continuously.

*Pink bollworm*

The incubation period is four to five days during all the months except December and January when it extends to seven days. The larval stage during the period from September to the end of November ranges between 10 and 14 days and in December and January 14 and 22 days. From the middle of November a few larvae enter the long-cycle stage. With the advance of the season larger number enter the long-cycle stage. Till the end of April, however, the short-cycle larvae are noticed on the standover crop. No pink bollworm is found in the crop after this period as there is no green boll on the plant. At Nagpur, the short-cycle larvae were not seen during June and July but there is some evidence to show their existence during these months at Akola (Table IX).

The pupal stage lasts for seven to nine days except in December and January when it occupies 10 to 12 days.

The duration of the life-cycle varies, in the case of the short-cycle, from 31 to 41 days during the coldest part ot the year and from 20 to 28 days during the rest of the year ; and in the case of the long-cycle, from eight to nine months.

Experiments carried out to find out the longevity of the moths showed that one female fed with sugar solution lived for 51 days and laid 205 eggs during her life. Another moth which lived for 31 days laid 343 eggs. Egg-laying occurs on a large scale from November to the end of February.

According to Ballard [1923], long-cycle pink bollworm larvae do not occur in south India. Husain, Bindra and others [1931] have definitely established that in the Punjab there are two types of life-cycles of *Platyedra gossypiella* Saund., the one in which the caterpillars immediately pupate at the end of their feeding period—the short-cycle ; and the other in which the caterpillars when full fed do not pupate but pass through a prolonged period of hibernation—the long-cycle. In that province even when a fairly large supply of flower buds and green bolls was made available during May and June, no pink bollworm larvae could be found and that the first brood of ' worms ' appearing in the cotton fields was the progeny of moths emerging in July and the beginning of August.

The pink bollworm seems to be capable of adapting itself to different environments. In south India there is no long-cycle stage as in the Punjab and the United Provinces. In the Hyderabad State it is found to attack early forms to an appreciable extent, whereas in the Punjab and the United Provinces this is not the case. In these provinces larger number of long-cycle larvae are found in the seeds whereas in Hyderabad they are in the soil.

## 'Carry-over' of the bollworms

In the Central Provinces and Berar, the last picking of cotton is finished by the end of December in normal years but in exceptional seasons it may extend to the end of January. The new crop is sown during the last week of June or the first week of July. There is thus a clear gap of five to six months between the close of one season and the commencement of the next. The bollworms have to tide over a long period when their food is either scanty or wanting. It is, therefore, necessary to know how they pass this critical period.

### *Spotted bollworm*

After cotton is harvested, the crop is allowed to stand for a considerably long period. This induces fresh growth and numerous buds and bolls appear till the end of April, which serve as food to spotted and pink bollworms and enable them to pass the period from January to April.

The time and method of removing the cotton stalks vary in different localities. In some places they are removed by hand pulling, in others, by cutting with a sickle or harrowing or ploughing. This is ordinarily done during February and March. At places during years of heavy rainfall the stalks are deliberately allowed to standover till the end of April for harvesting the *kapas* (seed cotton) of the second flush, known as '*faldari kapas*'. This practice, however, is in vogue in some parts of Berar only. The fields are ploughed by the end of May. Observations made by allowing the crop to standover during summer show that a fair number of bollworms harbour in the plants till the end of May but during June they practically disappear (Table IV).

Table IV

*Bollworm population in standover crop*

| Locality | Month and year of examination | No. of plants examined | Total No. of buds and bolls examined | Number and species of larvae found | | |
|---|---|---|---|---|---|---|
| | | | | *Earias fabia* | *P. gossypiella* | *H. obsoleta* |
| Akola | January 1935 | 100 | 392 | 6 | 38 | 0 |
| | March ,, | 100 | 589 | 12 | 32 | 0 |
| | April ,, | 500 | 2560 | 196 | 27 | 0 |
| | May ,, | 600 | 2376 | 76 | 1 | 0 |
| | June ,, | 150 | 107 | 1 | 0 | 0 |
| | February 1936 | 450 | 5840 | 125 | 277 | 0 |
| | March ,, | 750 | 7170 | 135 | 617 | 0 |
| | April ,, | 600 | 3815 | 258 | 430 | 0 |
| | May ,, | 1500 | 5782 | 128 | 4 | 0 |
| Nagpur | January 1935 | 200 | 1696 | 69 | 15 | 0 |
| | February ,, | 400 | 3969 | 214 | 26 | 0 |
| | March ,, | 500 | 5837 | 447 | 164 | 0 |
| | April ,, | 400 | 1619 | 220 | 39 | 0 |
| | May ,, | 400 | 1142 | 105 | 1 | 0 |
| | June ,, | 100 | 148 | 12 | 0 | 0 |

Ordinarily food is not available in the cotton fields during May and June. It can be concluded that the cotton fields do not appreciably help the spotted bollworm in tiding over the critical period.

*Alternative food plants*

In the cotton tract of the province elaborate irrigation facilities do not exist, but there are tanks or wells from which water is taken to raise a few vegetable and garden plants. In these places the food plants such as *bhindi* (*Hibiscus esculentus*), *ran-bhindi* (*Hibiscus panduriformis*), *ambadi* (*Hibiscus cannabinus*), *kandhi* (*Abutilon*), hollyhock (*Althaea rosea*) and *deokapas* or perennial cotton are found. Examination of these alternative food plants carried on during March to August 1935 and March to May 1936 showed that in *bhindi* and tree cotton infestation is carried over and a few specimens are found in *Abutilon* and *A. rosea* but in others the pest is practically absent. *Bhindi* is grown in summer in the vicinities of towns and villages for vegetable purposes. It is also imported from outside the province during the months of June and July. Examination of this material revealed the presence of the spotted bollworm. It is, therefore, quite possible that summer *bhindi* serves a fruitful source of reinfestation of the new crop.

*The pink bollworm*

In order to determine the various sources of reinfestation by the pink bollworm to the new cotton crop, a study of all possible sources such as soil, seed, *kapas*, stored cotton sticks, volunteer cotton plants and alternative host plants was made. The results are summarized below.

*Examination of soil*

For this purpose cotton stalks over half an acre area were removed before the first week of April in the year 1936. In May this area was dug uniformly up to a depth of 20 in. and at places where cracks were deeper up to 30 in. and the soil was carefully examined after sifting. 3641 empty cocoons of the spotted bollworm and 354 pink bollworm caterpillars were found. Out of these 354 caterpillars, 304 were found in flimsy cocoons either with fine grains of soil around them or in a wrapping of petals of withered flowers fallen on the ground. Fifty larvae were found in a free or naked state. No larva was found in the loose soil of the mulch of the top layer. Table V shows the number of larvae found at different depths.

TABLE V

*Number of pink bollworm larvae found in different layers*

| Depth of layers in inches | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | No. of larvae caught in sieve | Total |
|---|---|---|---|---|---|---|---|
| No. of pink bollworm larvae found | 9 | 45 | 133 | 15 | 1 | 151 | 354 |

While digging the soil $3\frac{1}{2}$ lb. of damaged *kapas* was gathered from the cracks and burrows of rats. A careful examination of this *kapas* did not disclose any pink bollworm larva.

There is no direct evidence to say that these caterpillars succeed in emerging as moths and reinfesting the new cotton crop. The fact, however, that the pink bollworm larvae are found on stray volunteer cotton plants during June to August (Table IX) leads one to believe that possibly some of the larvae resting in the soil develop into moths in the beginning of the monsoon.

*Examination of* kapas

To determine the number of larvae resting in the *kapas* picked from time to time, some quantity of it was taken from the lots harvested in November, December and January. It was examined by spreading the lint. All the pink bollworm larvae found in the lint were removed and the number recorded. The *kapas* was then ginned and the seed examined by cutting. The examination of *kapas* was done over two seasons, 1934-35 and 1935-36 (Table VI).

TABLE VI

*Number of pink bollworm larvae in unginned* kapas

| Date of picking | Nagpur | | | | Date of picking | Akola | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quantity of *kapas* examined in lb. | Period of examination | No. of pink bollworms found in | | | Quantity of *kapas* examined in lb. | Period of examination | No. of pink bollworms found in | |
| | | | Lint | Seed | | | | Lint | Seed |
| 24 Oct. 1934 | 1 | February | ... | ... | 25 Nov. 1934 | $2\frac{1}{2}$ | February | 13 | ... |
| 10 Nov. ,, | 1 | Do | ... | ... | 11 Dec. ,, | $2\frac{1}{2}$ | Do | 3 | 1 dead |
| 23 ,, ,, | 1 | Do | 2 | ... | 15 Jan. 1935 | $2\frac{1}{2}$ | Do | 21 | 4 |
| 7 Dec. ,, | 1 | Do | 6 | 4 | 26 Nov. ,, | 23 | Do | 2 | ... |
| 18 Jan. 1935 | $2\frac{1}{2}$ | Do | 7 | 5 | 12 Dec. ,, | 23 | Do | 8 | ... |
| 22 Nov. ,, | 20 | December | 3 | ... | 20 Jan. 1936 | 22 | Do | 10 | 3 |
| 20 Dec. ,, | 20 | January | 11 | ... | | | | | |
| 10 Jan. 1936 | 20 | February | 113 | 7 | | | | | |

It will be seen that cotton of late pickings harbours greater number of pink bollworm than of early pickings and it is in the lint that a large number is found. This is also the case in the Punjab where Bindra [1928] states that the infestation is higher in the middle pickings of *kapas* than in early ones and highest in samples of late pickings.

*Examination of seed* (sarki)

With a view to determine how the pest behaves in the province with regard to its hibernation in cotton seed, seed of different pickings was examined from time to time. The results are given in Table VII.

TABLE VII

*Number of pink bollworm larvae in cotton seed*

| Picking | Type of seed | Date or period of examination | Quantity of seed in lb. | No. of pink bollworm larvae found in | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | free state | single seed | double seed | flimsy cocoon | Total | |
| | | | 1934-35 (Akola) | | | | | | |
| I & II . . | V. 434 | February | 2½ | ... | ... | ... | ... | ... | |
| III & IV . | Do | Do | 2½ | ... | ... | ... | ... | 1 | dead |
| Mixed picking . | Ak. sp. Buri | Do | 1 | 3 | ... | ... | ... | 3 | |
| | | | 1934-35 (Nagpur) | | | | | | |
| Mixed picking . | ... | February | 1 | 7 | ... | ... | ... | 7 | brought from market |
| | | | 1935-36 (Akola) | | | | | | |
| Nov. I & II mixed | V. 434 | 17 Dec. 1935 | 5 | 16 | ... | ... | ... | 16 | low grade |
| Do . . | Do | 30 Dec. 1935 | 5 | 2 | ... | ... | ... | 2 | ungraded |
| Nov. & Dec. mixed | Buri | 5 Feb. 1936 | 10 | 8 | 1 | ... | 3 | 12 | |
| Mixed . . | Roseum | 17 Feb. 1936 | 10 | 1 | 1 | ... | ... | 2 | |
| Do . | Bazar seed | 17 Feb. 1936 | 20 | 4 | ... | ... | ... | 4 | only one larva healthy |
| Do . . | Cambodia | 25 May 1936 | 15 | 1 | ... | ... | ... | 1 | not able to pupate |
| Do . . | Bazar . | 20 May 1936 | 20 | ... | ... | ... | ... | ... | |
| Do . . | Buri . | 26 May 1936 | 20 | ... | ... | ... | ... | ... | |

It will be seen from the above table that the number of pink bollworm larvae in seed is very small. Those found during December to February either emerge as moths or die due to heat during succeeding months. This leads to the conclusion that in the Central Provinces and Berar, the seed is not the main source of infection of the crop of the next season.

*Examination of stored cotton stalks*

After *kapas* is gathered some imperfectly developed bolls and damaged locks are left on the plants in the field. Pink bollworm larvae present in them

are thus carried to the place where cotton stalks are stored for fuel or for thatching purposes. These stalks were examined for the larvae. The results show that the cotton stalks harbour long-cycle larvae to a small extent and serve to carry infestation to some degree to the next season (Table VIII).

TABLE VIII

*Number of pink bollworm in dry cotton stalks*

| Date of examination | Quantity in lb. of stalks examined | Quantity in lb. of *kapas* gathered | No. of pink bollworm larvae found | Remarks |
|---|---|---|---|---|
| | | *Nagpur* | | |
| 28 Mar. 1935 | 160 | ½ | *Nil* | Stalks were stored for this purpose both at Nagpur and Akola farms |
| 28 Apr. " | Do | ½ | 2 | |
| 28 May " | Do | ½ | *Nil* | |
| 28 June " | Do | ½ | *Nil* | |
| 28 Mar. 1936 | Do | *Nil* | 2 | |
| 21 Apr. " | Do | *Nil* | 1 | |
| 26 May " | Do | *Nil* | *Nil* | |
| | | *Akola* | | |
| 28 Mar. 1935 | 160 | 6 | 3 | |
| 28 Apr. " | Do | 5 | 4 | |
| 28 May " | Do | 3 | 1 | |
| 28 June " | Do | 3¼ | 4 | |
| 13 Apr. 1936 | Do | 9 oz. | 4 | Stalks were stored by a cultivator on the 5th mile of Akola-Basim Road |
| 20 May " | Do | 1½ | 1 | Stalks were stored on the Government Farm |
| 6 June " | Do | ¾ | 17 | Stalks were stored by a cultivator at Hinga village near Government Farm |

*Examination of volunteer or stray cotton plants*

Buds and bolls from stray volunteer cotton plants were collected and examined and the number of bollworms noted. These plants serve as breeding places for pink bollworm during the months June and July as the moths emerging from cotton fields in these months find food plants readily available for oviposition (Table IX).

TABLE IX

*Number of bollworms in stray volunteer cotton plants*

| Locality | Date of examination | No. of plants examined | No. of forms | | No. of bollworms | | Remarks |
|---|---|---|---|---|---|---|---|
| | | | Buds | Bolls | Spotted bollworm | Pink bollworm | |
| Govt. Farm, Akola | 1 July 1935 | 121 | 120 | 2 | 5 | 20 | Plants were found in fodder plot |
| Umri village near Akola | 23 June 1936 | 50 | 131 | 10 | 6 | 37 | Some larvae pupated on 26 June 1936 and emerged as moths on 3 July 1936 |
| | 3 July 1936 | 50 | 65 | 7 | 11 | 5 | Material collected from the same plants as above |
| | 20 July 1936 | 50 | 289 | 6 | 7 | 107 | All larvae except four were small |
| Ginning Factory, Akola | 12 June 1936 | ... | 46 | 6 | ... | ... | Plants were near tank |
| | 7 July 1936 | ... | 34 | 4 | ... | ... | Same plants as above |
| Nagpur | 18-31 Aug. 1936 | 150 | 390 | 326 | 2 | 16 | Material was collected from ratoon plants kept at Nagpur |
| | 8 Sept. 1936 | 50 | 147 | 322 | 6 | 6 | Do |

*Examination of alternative food plants*

Though cotton is the most favoured food plant of the pink bollworm, it is sometimes found on *bhindi*, hollyhock and *abutilon*, but their number in them is so small that they can hardly be considered as sources of infestation. Observations carried out during March to August 1935 and March to May 1936 on the alternative host plants of *E. fabia* showed that it is only the tree cotton in which a fairly large number of pink bollworms were found, one or two caterpillars were seen in *A. rosea* and *H. sabdarifa* but these can safely be ignored as means of carry-over. The perennial and volunteer cotton plants are thus the real sources of danger. The following observation gives an idea of the seriousness of this source.

At Chimur, a village in Chanda district, survey was made of the perennial cotton plants in April 1936 and about 100 plants were found growing. From one plant about 7 ft. high and in full bearing, 50 forms were removed and examined. Out of these, 24 were bolls and 26 flower buds. Twenty-two bolls were found attacked by the pink bollworms and from them 22 larvae were collected alive.

*Emergence of pink bollworm moths from stored* kapas *and seed*

*Kapas* (unginned cotton) and seed (*sarki*) of different pickings were stored in suitable containers and the number of moths emerged was recorded every week. Not a single moth emerged from 2½ lb. of *kapas* of different pickings kept under observation at Akola from February to September 1935. From 20 lb. of *kapas* similarly kept for the same period during 1936, 13 moths emerged, two from the *kapas* of November picking in the last week of February, three from that of December picking in February and one in April. At Nagpur also during 1935, from 1 lb. of *kapas* of three pickings each, not a single moth was obtained. From 20 lb.of *kapas* in 1936 kept over the same period, four moths were obtained from the *kapas* of November picking about the beginning of May, 10 from the *kapas* of December picking, three in April, five in August and two in September ; and from the January picking, 25 moths emerged, three in April, 20 in August and two in early September.

At Akola, 5 lb. of cotton seed kept from February to September 1935 did not provide a single moth. In 1936, during the same period, 43 lb. of seed were kept under observation and from this lot one moth was obtained from seed of November picking in March, and six from that of December picking, one in February and five in March ; and one from January picking in February.

At Nagpur, 4 lb. of cotton seed were kept in 1935 and 43 lb. in 1936 over the same period, i.e. February to September. Two moths emerged in July 1935 from seed brought from bazar. In 1936, in all 20 moths emerged ; five from seed of the November picking in the month of April, five from that of December picking—three in April and two in August—and ten from the January picking—two in April to May and eight in the first week of August.

The above figures show that *kapas* is not a serious source of reinfection. The only possible danger is from moths which emerge during July and August. The local practice of the cultivators of selling away all *kapas* and not storing it obviates this danger.

There is a negligible number of long-cycle larvae in the seed and the possibility of these developing into adults is greatly minimized when stored in large heaps. Husain, Bindra and others [1931] also support this view when they say that only 1 or 2 per cent of the resting caterpillars reach the moth stage in case of large stores and 6 to 9 per cent in case of small stores.

## Feasibility of adopting clean-up measures

*Off-season*

The period between the close of one cotton season and the beginning of the next is long enough to expose the bollworms to dangers of starvation. The early cleaning of cotton fields involves no extra expenditure and prevents the soil from getting impoverished ; and it also derives maximum benefit from exposure to sun.

*Hot weather* bhindi

As already pointed out, *bhindi* serves a rich breeding place for almost all pests of cotton which travel on to new cotton crop in the field. Hot weather *bhindi* is grown on a small scale near towns and is not a paying crop as it is

heavily infested with pests and at several places suffers from shortage of water. Even if the crop pays during certain years, to safeguard the larger interests of the cotton growers, its cultivation in summer months should be stopped by all possible measures.

*Tree cotton*

There is hardly any propriety of growing perennial cotton except as fancy or to have some quantity of lint for preparing wicks for lamps in the daily worship of family gods. There are only stray plants but they are capable of harbouring the pests. By explaining the possible danger from the tree cotton people could be persuaded to remove them.

*Other food plants*

Some alternative host plants grow in flower or fruit gardens. They are of no economic importance. They are allowed to grow as perhaps it is not realized that they serve as sources of reinfection of cotton pests. If the garden-owners are made aware of the possible harm from these plants, there should be no difficulty in inducing them to keep their gardens free from them.

In short, it does not seem to be very difficult to starve out the bollworms during the non-cotton growing period by adopting the clean-up measures.

## Summary


Three types of cotton bollworms, i.e. the pink bollworm (*Platyedra gossypiella* Saund.), the spotted bollworm (*Earias fabia* Stoll.) and the American bollworm (*Heliothis obsoleta* Fabr.) are found to attack cotton in the Central Provinces and Berar.

Spotted bollworm is carried over from one season to another by the alternative food plants such as *H. esculentus*, *H. panduriformis*, *H. sabdarifa*, *Abutilon*, hollyhock, perennial and stray cotton plants.

The status and behaviour of the spotted bollworm is the same as in Gujrat and adoption of clean-up measures is the only way of its control.

*Kapas* of late pickings harbours a fairly good number of pink bollworm larvae but the practice of selling it away before summer and the severe heat of the season make it difficult for the pest to ‘ carry-over ’.

The pink bollworm larvae do not hibernate in the cotton seed to the extent necessary to carry infection to the next year.

Cotton stalks stored for fuel provide place for some larvae to aestivate and there emerge as moths in June and July but for want of grown-up food plants during these months their activity is retarded.

In the province, as most of the rain is received during July and August, it is very detrimental to the larvae in the soil and moths in the field.

Stray volunteer cotton plants and the tree cotton plants harbour many pink bollworm larvae during June and July but the number of such plants is too small to apprehend any danger of heavy reinfestation. They, however, serve as food for the pink bollworm during the critical period.

Early removal of cotton stalks after the last picking and prevention of volunteer cotton and tree cotton and disposal of all *kapas* before May are the methods to prevent any serious damage by the pink bollworm.

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## APPENDIX I

### Table A

*Average monthly rainfall at Nagpur and Akola*

| Month | Average of 61 years at Nagpur | Average of 5 years at Akola |
|---|---|---|
| April | 0·39 | 0·01 |
| May | 0·77 | 0·52 |
| June | 7·88 | 4·17 |
| July | 13·21 | 8·12 |
| August | 11·90 | 7·30 |
| September | 9·56 | 7·99 |
| October | 3·64 | 2·61 |
| November | 0·21 | 1·26 |
| December | 0·59 | 0·11 |
| January | 0·05 | 0·04 |
| February | 0·13 | 0·29 |
| March | 0·11 | 0·02 |

### Table B

*Average monthly humidity at Akola*

| Month | Year | | |
|---|---|---|---|
| | 1934 | 1935 | 1936 |
| January | 57·5 | 62·2 | 53·7 |
| February | 37·0 | 49·0 | 72·7 |
| March | 31·0 | 28·0 | 42·5 |
| April | 28·0 | 34·0 | 27·0 |
| May | 19·5 | 20·5 | 35·5 |
| June | 30·5 | 62·6 | 77·2 |
| July | 83·6 | 89·0 | 85·4 |
| August | 86·8 | 85·4 | 82·0 |
| September | 87·5 | 84·2 | 85·1 |
| October | 62·0 | 62·8 | 65·7 |
| November | 68·8 | 55·5 | 72·6 |
| December | 66·1 | 62·4 | 69·9 |

## APPENDIX II

### Table A

*Bollworm population in standing crop*

| Locality | Month and year of examination | No. of plants examined | No. of buds and bolls examined | No. and species of larvae found | | |
|---|---|---|---|---|---|---|
| | | | | *E. fabia* | *P. gossypiella* | *H. obsoleta* |
| Akola . | September 1935 | 600 | 5292 | 17 | 0 | 54 |
| | October ,, | 600 | 5308 | 142 | 21 | 18 |
| | November ,, | 600 | 3746 | 401 | 86 | 0 |
| | December ,, | 750 | 3660 | 446 | 153 | 0 |
| | January 1936 | 600 | 3203 | 185 | 402 | 1 |
| | September ,, | 100 | 1448 | 3 | 1 | 1 |
| | October ,, | 100 | 1400 | 56 | 10 | 0 |
| | November ,, | 100 | 398 | 25 | 47 | 0 |
| | December ,, | 100 | 905 | 27 | 39 | 0 |
| | August 1934 | *In situ* No. of plants not recorded | 3302 | 6 | 0 | 0 |
| Nagpur | September 1934 | Do | 24804 | 36 | 0 | 2 |
| | October ,, | Do | 24676 | 188 | 0 | 22 |
| | November ,, | Do | 16393 | 444 | 4 | 1 |
| | December ,, | Do | 15505 | 780 | 67 | 0 |
| | September 1935 | 300 | 10833 | 111 | 0 | 0 |
| | October ,, | 200 | 3061 | 28 | 1 | 0 |
| | November ,, | 400 | 5569 | 109 | 9 | 0 |
| | December ,, | 500 | 5541 | 129 | 53 | 0 |
| | January 1936 | 400 | 5514 | 95 | 29 | 0 |
| | February ,, | 200 | 2514 | 40 | 6 | 0 |
| | August ,, | 150 | 280 | 0 | 0 | 0 |
| | September ,, | 600 | 4286 | 2 | 0 | 2 |
| | October ,, | 600 | 5235 | 42 | 8 | 1 |
| | November ,, | 750 | 3470 | 131 | 15 | 0 |
| | December ,, | 600 | 2078 | 98 | 16 | 0 |
| | January 1937 | 300 | 929 | 17 | 3 | 0 |

TABLE B

*Bollworm population in shed forms*

| Locality | Month and year of examination | Total No. of plants examined | Total number of shed buds and bolls examined | Number and species of larvae found | | |
|---|---|---|---|---|---|---|
| | | | | *E. fabia* | *P. gossypiella* | *H. obsoleta* |
| Akola | April 1935 | 350 | 1487 | 85 | 3 | 0 |
| | May ,, | 350 | 725 | 14 | 0 | 0 |
| | June ,, | 350 | 24 | 0 | 0 | 0 |
| | September ,, | 500 | 1062 | 17 | 0 | 50 |
| | October ,, | 500 | 2134 | 121 | 3 | 38 |
| | November ,, | 500 | 1016 | 216 | 3 | 0 |
| | December ,, | 500 | 429 | 80 | 3 | 0 |
| | January 1936 | 500 | 369 | 38 | 27 | 0 |
| Nagpur | September 1935 | 300 | 465 | 29 | 1 | 1 |
| | October ,, | 300 | 2417 | 25 | 0 | 2 |
| | November ,, | 300 | 1242 | 33 | 0 | 0 |

# DIFFERENTIATION OF HYDROGEN CLAYS AND HYDROGEN BENTONITES AND IDENTIFICATION OF MINERAL CONSTITUENTS CONTAINED IN THEM BY ELECTRO-CHEMICAL METHODS

## II. MONTMORILLONITIC CLAYS AND BENTONITES*

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(Received for publication on 30 April 1942)

(With five text-figures)

IN the previous part [Mukherjee, Mitra, Bagchi and Mitra, 1942] the electro-chemical features of kaolinite and some kaolinitic hydrogen clays have been discussed. This part deals with one hydrogen clay and two hydrogen bentonites prepared from entire clay fractions which gave dehydration curves similar to that of montmorillonitic clay minerals. Results obtained with six sub-fractions isolated from one of the entire hydrogen bentonite fractions have also been presented. Particulars regarding the hydrogen clay and the hydrogen bentonites have been given in Table I. Investigations on the viscous and related properties of bentonites are being carried out in this laboratory under a scheme of research financed by the Assam Oil Company and some results have been published el ewhere [Mukherjee and Sen Gupta, 1940 ; Mukherjee, Sen Gupta and Reid, 1940]. The present investigation is mainly concerned with the electro-chemical properties of these systems and the importance of the electro-chemical data in differentiating hydrogen clays and hydrogen bentonites and also in identifying their principal mineral constituents.

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*Most of the results given in this paper have been taken from the published Annual Report for 1939-40 on the working of a scheme of Research into the Properties of Colloid Soil Constituents financed by the Imperial Council of Agricultural Research, India, and directed by Professor J. N. Mukherjee

**Senior Assistant Soil Chemist under the above scheme

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TABLE I

*Particulars regarding hydrogen clay and hydrogen bentonites used*

| Description of soil or bentonite from which the hydrogen clay or hydrogen bentonite was isolated | Reference number of corresponding hydrogen clay or hydrogen bentonite | Equivalent spherical diameter in microns |
|---|---|---|
| Non-lateritic calcareous soil (B-type) from Government farm at Padegaon (Lab. No. 46) | Padegaon-B . . | <2·0* |
| White bentonite from Bhadres (Lab. No. B. O. C. 3) | Bhadres-B . . | <2·0* |
| Grey white bentonite from Hati-ki-Dhani (Lab. No. B. O. C. 1) | Hati-ki-Dhani-B . | <2·0* |
| Do. . . . . | Do. $B_1$ . | 0·5 to 1·0 |
| Do. . . . . | Do. $B_2$ . | 0·25 to 0·5 |
| Do. . . . . | Do. $B_3$ . | 0·10 to 0·25 |
| Do. . . . . | Do. $B_4$ . | 0·05 to 0·10 |
| Do. . . . . | Do. $B_5$ . | 0·025 to 0·05 |
| Do. . . . . | Do. $B_6$ . | 0·025 |

*Entire clay fractions

## EXPERIMENTAL

The methods of preparation of the hydrogen clays and hydrogen bentonites, their electrometric titration with bases and fusion analysis have been full described elsewhere [Mitra, 1936, 1940]. For the separation of the six sub-fractions from the entire hydrogen bentonite fraction Hati-ki-Dhani-B, Ayres' method as described by Whitt and Baver [1937] was followed. The dehydration curves were obtained by the method of Kelley *et al.* [1936].

## RESULTS

### (a) *Properties of entire hydrogen clay and hydrogen bentonite fractions*

The results of fusion analysis and the base exchange capacities (per 100 gm.) calculated from titration curves in the presence and absence of salts have been given in Tables II and III. The titration curves are shown in Figs. 1, 2 and 3 and the dehydration curves in Fig. 4.

Unlike the dehydration curves which have more or less the same form and resemble those of montmorillonitic clay minerals [Kelley, *et al.* 1936], the titration curves show very dissimilar features. These are summarized in Table III-A.*

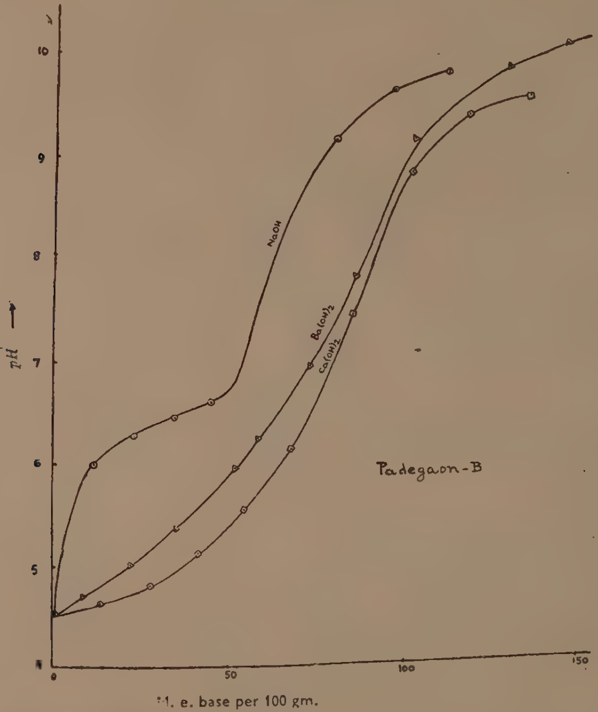


FIG. 1. Potentiometric titration curves of Padegaon-B with different bases

TABLE II

*Chemical compositions of entire hydrogen clay and hydrogen bentonites on the ignited base*

| Reference number of hydrogen clay or hydrogen bentonite | $SiO_2$ (per cent) | $Al_2O_3$ (per cent) | $Fe_2O_3$ (per cent) | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{R_2O_3}$ |
|---|---|---|---|---|---|
| Padegaon-B . . . | 56·4 | 26·7 | 16·9 | 3·58 | 2·51 |
| Bhadres-B . . . | 60·4 | 35·0 | 4·4 | 2·93 | 2·70 |
| Hati-ki-Dhani-B . . . | 59·0 | 29·0 | 9·6 | 3·46 | 2·86 |

*For detailed discussions of the features of titration curves of hydrogen clays obtained from various Indian soils, the reader is referred to Mitra [1936, 1940], Mukherjee, Mitra and Mukherjee [1937] and Mukherjee, Mitra, Chatterjee and Mukherjee [1942]

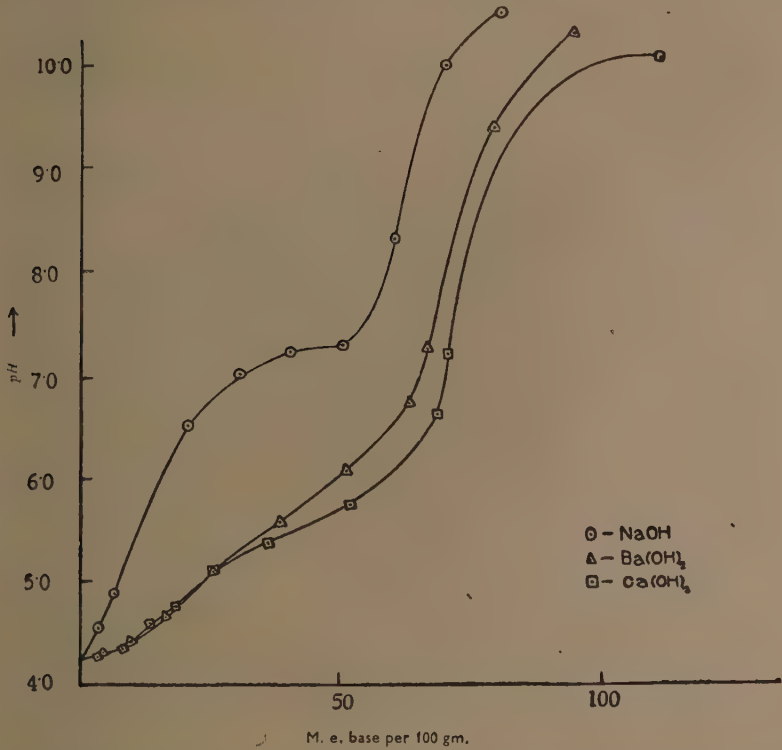


FIG. 2. Potentiometric titration curves with different bases of hydrogen bentonite Hati-ki-Dhani-B

TABLE III

*Base exchange capacities of entire hydrogen clay and hydrogen bentonites calculated from titration curves*

| System | Base exchange capacity in m. e. base for 100 gm. oven dried colloid using | | | | | |
|---|---|---|---|---|---|---|
| | NaOH | | $Ba(OH)_2$ | | $Ca(OH)_2$ | |
| | At inflexion point | At $p$H 7·0 | At inflexion $p$H point | At $p$H 7·0 | At inflexion point | At $p$H 7·0 |
| Padegaon-B . . | 57·0(7·4)* | 53·5 | 89·0(8·05) | 74·0 | 94·0(8·1) | 82·0 |
| Bhadres-B . . . | 52·5(8·1) | 27·5 | 71·0(7·4) | 67·5 | 72·0(6·85) | 72·5 |
| Hati-ki-Dhani-B . . | 62·5(8·8) | 30·0 | 66·2(7·3) | 64·8 | 70·2(7·2) | 69·2 |
| Hati-ki-Dhani-B+0·1$N$ NaCl | 74·5(6·8) | 76·0 | .. | .. | .. | .. |
| Hati-ki-Dhani-B+0·1$N$ $BaCl_2$ | .. | .. | 89·0(7·0) | 89·0 | .. | .. |
| Hati-ki-Dhani-B+0·1$N$ $CaCl_2$ | .. | .. | .. | .. | 82·5(7·0) | 82·5 |

*The figures in brackets denote the $p$H at the inflexion point; the base exchange capacities of the Hati-ki-Dhani-B series at the second inflexion point have been given.

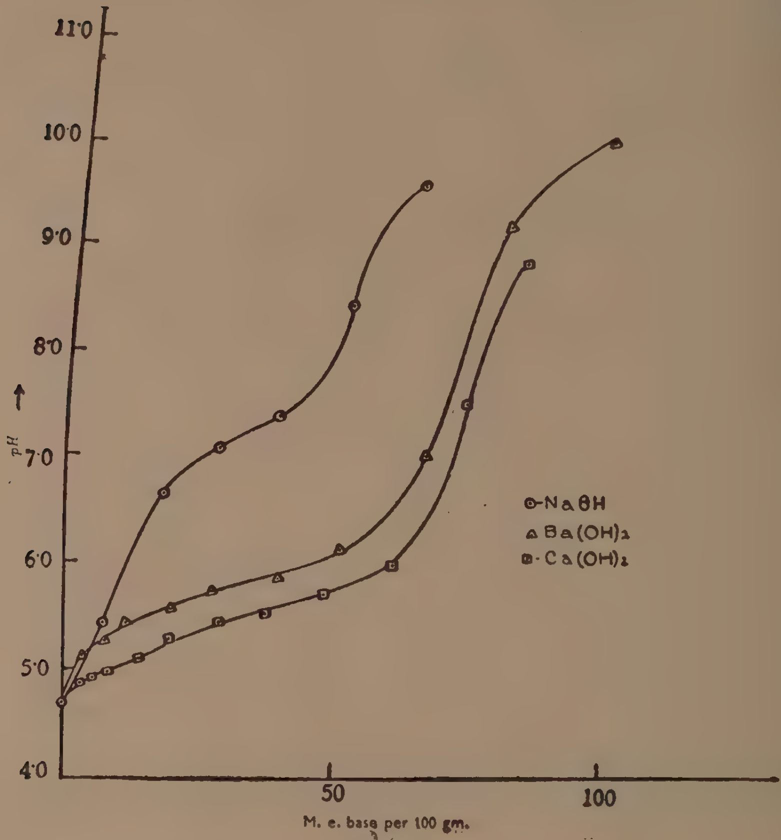


FIG. 3. Potentiometric titration curves with different bases of hydrogen bentonite Bhadres-B

TABLE III-A

| System | Nature of titration curve with | | |
|---|---|---|---|
| | NaOH | $Ba(OH)_2$ | $Ca(OH)_2$ |
| Padegaon-B | Weak, monobasic | Strong, monobasic | Strong, monobasic |
| Bhadres-B | Weak, monobasic | Weak, monobasic | Weak, monobasic |
| Hati-ki-Dhani-B | Moderately strong, dibasic | Moderately strong, dibasic | Moderately strong dibasic |

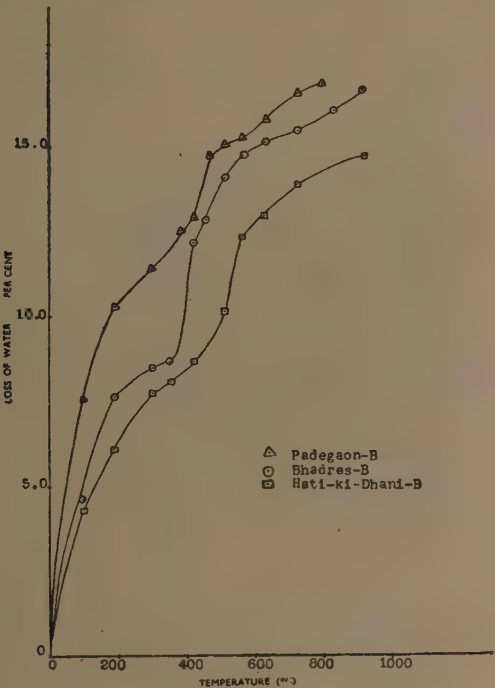


FIG. 4. Dehydration curves of hydrogen clay and hydrogen bentonites

Interesting correlations between the nature of the titration curves and some viscous properties of hydrogen bentonites have been observed by Mukherjee, Sen Gupta and Reid [1940]. According to them, dibasic bentonites such as Hati-ki-Dhani-B are more suitable as drilling muds than the monobasic ones, e.g. Bhadres-B.

The base exchange capacities, calculated from the titration curves, have comparatively high values (Table III) as is to be expected in the case of montmorillonitic clays.

The data recorded in Table II show that Padegaon-B, Hati-ki-Dhani-B and Bhadres-B have markedly different chemical compositions. The percentages of $Al_2O_3$ and $Fe_2O_3$ in the two hydrogen bentonites are materially different. Their $SiO_2/R_2O_3$ ratios and the $SiO_2/Al_2O_3$ ratio of Bhadres-B approximate those of beidellite rather than montmorillonite. A part of the Al of the gibbsite layer may have been replaced by Fe, especially in Hati-ki-Dhani-B. It would explain the slightly higher value of the $SiO_2/Al_2O_3$ ratio of Hati-ki-Dhani-B compared with that of beidellite. Presence of iron oxide is possible particularly in the hydrogen clay Padegaon-B which has a comparatively large percentage of Fe, and would account for the observation that both the $SiO_2/Al_2O_3$ and $SiO_2/R_2O_3$ ratios of this hydrogen clay differ materially from the corresponding ratios calculated for either montmorillonite or beidellite. These explanations, however, must be accepted with reservation in view of the heterogeneous character of the entire clay fraction and the possibility of its containing more than one clay mineral. The various sub-fractions of the

entire clay may not necessarily contain one and the same clay mineral (see next section ; also, Mitra [1942]) and in such cases the average results of fusion analysis and dehydration studies obtained with the ensemble (i.e. the entire clay fraction) are of little value for the differentiation and identification of its various mineral constituents.

Apart from the differences mentioned above the two hydrogen bentonites reveal the following common features also observed by us with hydrogen clays [Mitra, 1936, 1940 ; Mitra, Mukherjee (S) and Bagchi, 1940 ; Mukherjee (J. N.), Mitra and Mukherjee (S), 1937].

(*i*) The base exchange capacity depends on *p*H and cation effects. The *p*H effect is brought out by the fact that the greater the *p*H the greater is the base exchange capacity calculated from the titration curves. The cation effect is illustrated by (*a*) the dependence on the cation of the base of the base exchange capacity calculated at the inflexion point of the titration curves and more strikingly at a fixed *p*H, e.g. *p*H 7·0 and (*b*) by the much higher base exchange capacity obtained on titration in the presence of a large concentration of a neutral salt than in its absence (Table III). In the absence of salts the base exchange capacity decreases in order $Ca(OH)_2 > Ba(OH)_2 > NaOH$ which, however, the changes to $Ba(OH)_2 > Ca(OH)_2 > NaOH$ in the presence of a fixed concentration of the corresponding salts. In the presence of salts the cation effect $Ba^{++} > Ca^{++} > Na^+$ is regular in the sense that it follows the lyotrope series and is determined by the order of electrical adsorption of the cations [Mukherjee, 1922] together with their hydration envelopes. In the absence of salts the cations are probably adsorbed in a dehydrated condition which accounts for the irregular or specific cation effect, irregular in the sense that it does not follow the lyotrope series, operating under these conditions.

(*ii*) The titration curves with NaOH, $Ba(OH)_2$ and $Ca(OH)_2$ of any one of the two hydrogen bentonites though showing the same broad features are not mutually superimposable but have very different slopes at one and the same *p*H. The buffer capacity (at a given *p*H) which is the reciprocal of this slope follows the order $Ca(OH)_2 > Ba(OH)_2 > NaOH$, in agreement with the irregular cation effect.

(*iii*) The ratio of the free acid (i.e. the $H^+$ ion concentration*) to the total neutralizable acid calculated at the inflexion point is, with both hydrogen bentonites, of the order of $10^{-2}$. This in the classical sense means that the acids are very weakly dissociated. The titration curves of Bhadres-B present features which are in harmony with this conclusion. Those of Hati-ki-Dhani-B, however, instead of showing a weak acid character have the appearance of the titration curve of a moderately strong dibasic acid.

(*b*) *Properties of sub-fractions of hydrogen bentonite*

The chemical compositions and the base exchange capacities (per 100 gm. and per sq. cm. of the average external surface) calculated at the second inflexion point of potentiometric titration curves with NaOH are given in Tables IV and V. Fig 5 shows the titration curves of four out of the six sub-fractions. The dehydration curves of the sub-fractions have not been separately determined.

*The $H^+$ ion concentration depends on the amount of the disperse phase in a given volume of the sol. In this work, 2·5 per cent suspensions were used

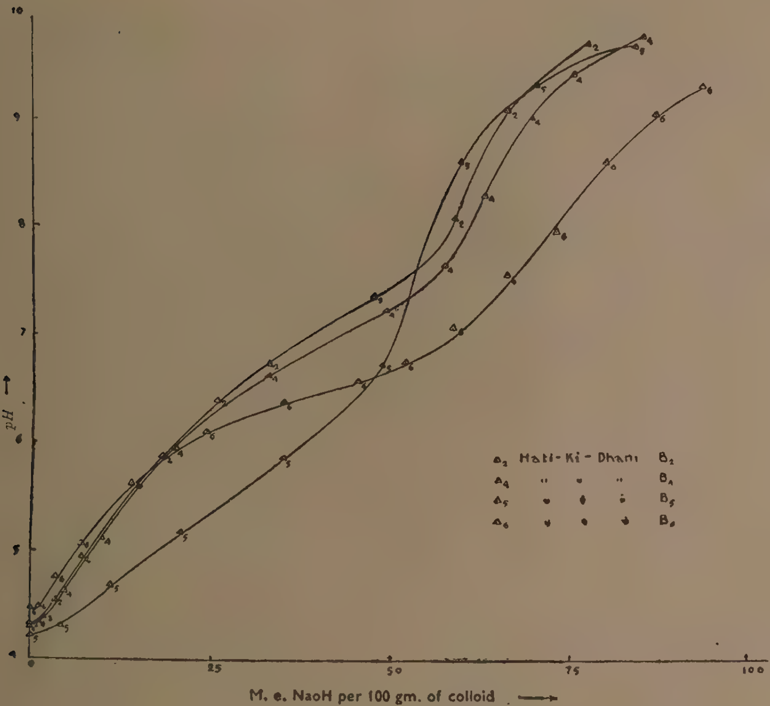

FIG. 5. Potentiometric titration curves with NaOH of sub-fractions of hydrogen bentonite

TABLE IV

*Chemical compositions of sub-fractions of hydrogen bentonite*

| Reference No. of sub-fraction | Reference No. of corresponding hydrogen bentonite | Chemical composition (on the ignited basis) | | | | |
|---|---|---|---|---|---|---|
| | | $SiO_2$ (per cent) | $Al_2O_3$ (per cent) | $Fe_2O_3$ (per cent) | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{R_2O_3}$ |
| 1 | Hati-ki-Dhani-$B_1$ . | 58·8 | 28·5 | 11·2 | 3·51 | 2·63 |
| 2 | $B_2$ . | 58·3 | 22·1 | 15·4 | 4·46 | 3·08 |
| 3 | $B_3$ . | 58·4 | 23·9 | 15·3 | 4·15 | 2·95 |
| 4 | $B_4$ . | 58·4 | 24·6 | 14·5 | 4·04 | 2·88 |
| 5 | $B_5$ . | 56·7 | 31·4 | 9·3 | 3·07 | 2·58 |
| 6 | $B_6$ . | 60·6 | 23·0 | 14·4 | 4·48 | 3·21 |

TABLE V

*Base exchange capacities per gm. and per sq. cm. of surface of sub-fractions of hydrogen bentonite*

| Reference number of sub-fraction | Reference number of hydrogen bentonite | Base exchange capacity at second inflexion point of titration curve with NaOH | |
|---|---|---|---|
| | | Per gm. | Per sq. cm. of surface × $10^7$ |
| 1 | Hati-ki-Dhani-$B_1$ . . . | 0·49(8·38)* | 166·0 |
| 2 | $B_2$ . . . | 0·58(8·13) | 98·0 |
| 3 | $B_3$ . . . | 0·59(8·13) | 44·5 |
| 4 | $B_4$ . . . | 0·62(8·10) | 21·0 |
| 5 | $B_5$ . . . | 0·55(8·13) | 9·5 |
| 6 | $B_6$ . . . | 0·75(8·33) | <8·5 |

The different sub-fractions do not have identical properties. The variations with diminishing particle size may be summed up as follows :—

| Chemical composition | Base exchange capacity | | Form of titration curves |
|---|---|---|---|
| | Per gm. | Per sq. cm. of surface | |
| Variations though definite are not regular. They are very marked for fraction one and especially fraction five | Increases except for fraction five | Decreases . . | Similar except for fraction one and especially fraction five |

*The figures in brackets denote the $pH$ at the second inflexion point

Judging from the silica-alumina ratios, sub-fractions 2,3, 4 and 6 are likely to contain montmorillonite. Their titration curves have the same form. Fe is perhaps mainly present as free ferric oxide in them. The slightly higher values of the above ratio than 4·0 may be due to the presence of some free silica and/or the replacement of a small fraction of the gibbsitic Al for Fe. The $SiO_2/R_2O_3$ ratios of these fractions, on the other hand, also admit of the explanation that they are mainly made up of beidellite whose Al has been partially replaced by Fe. The $SiO_2/Al_2O_3$ ratio of fractions 1 and 5 is nearer to that of beidellite than montmorillonite. The agreement is very close in the case of fraction 5. This considered with the fact that fraction 1 and especially fraction 5 give titration curves which have markedly dissimilar features compared with the other four sub-fractions suggests that the above two fractions are made up of a different mineral, perhaps beidellite. The Fe is mainly present in them as free ferric oxide. Fraction 5, in particular, appears to be made up of beidellite and small quantities of free ferric oxide. Unpublished work of Mr S. N. Bagchi shows that fraction 5 has refractive index and appearance under the microscope quite different from the other fractions.

The differences in the base exchange capacities of the various fractions may be due, at least in part, to their having different specific surfaces. Where the chemical composition does not show material differences as in the case of fractions 2, 3, 4 and 6, the difference in the base exchange capacity may arise from this cause. The finer the fraction the greater will be the base exchange capacity, assuming that the interaction with the base is confined to the outer surface. The results given in Table V, on the other hand, show that the base exchange capacity calculated per sq. cm. of the external surface (Ts) increases with the particle size. A constant value of Ts would be observed if the base exchange capacity were determined by the external surface alone. The variations actually observed show that the reaction with the base is not confined to the outer surface. The particles have considerable inner surfaces and/or fresh layers are progressively exposed as the reaction with the alkali proceeds.

## Summary

Two hydrogen bentonites and one hydrogen clay prepared from two Indian bentonites and a calcareous soil from Padegaon (Poona) which give dehydration curves similar to those of montmorillonitic clay minerals have different chemical compositions and their titration curves with bases show markedly dissimilar features. One of the hydrogen bentonites behaves as a weak monobasic acid, and the other as a moderately strong dibasic acid judged from the nature of the titration curves with NaOH, $Ba(OH)_2$ and $Ca(OH)_2$. The NaOH curve reveals a weak monobasic acid character of the hydrogen clay. Its $Ba(OH)_2$ and $Ca(OH)_2$ curves have the appearance of that of a strong monobasic acid.

Four out of six sub-fractions of the dibasic hydrogen bentonite have approximately the same chemical composition and their titration curves have practically the same form. The remaining two sub-fractions, especially one of them, have quite different chemical compositions, and their titration curves present features not observed in those of the other four sub-fractions.

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# FRACTIONATION OF SOIL PHOSPHORUS

## I. METHOD OF EXTRACTION

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(Received for publication on 27 February 1942)

(With three text-figures)

DEAN [1938] in an attempted fractionation of the soil phosphorus showed that by extracting the soil successively with alkali and acid, it was possible to divide the phosphorus compounds of the soil into three broad divisions, viz. (*a*) organic compounds soluble in sodium hydroxide, (*b*) inorganic compounds dissolved by sodium hydroxide followed by an acid, and (*c*) insoluble compounds. The methods of extraction and determination of the fractions adopted by him were more or less empirical in nature. This study was undertaken at the Rothamsted Experimental Station as an extension on Dean's work carried out in the same laboratory. In a method of fractionation which is based on extraction, it is essential that the extraction should be as thorough and complete as possible and that there should not be any transformation of one fraction into the other during extraction and determination. The object of the present work was to make a critical examination of the method employed by Dean with special reference to the conditions of extraction. In an earlier communication by the author [Ghani, 1942] an improved procedure for the determination of organic phosphorus in the alkali-soluble fraction has been described.

### Removal of exchangeable bases before alkali extraction

It was repeatedly observed by the earlier workers that alkali-soluble phosphorus increased if the soil was treated with a dilute acid. The effect of the acid upon the soil may be partly to break up soil particles and thus expose more phosphate to the subsequent alkali extraction and partly to remove exchangeable calcium which would otherwise precipitate a part of the phosphorus dissolved by the alkali. Schollenberger [1918, 1920] in his study of the soil organic phosphorus used different acids of varying strength for pretreating the soil before ammonia extraction and found that alkali-soluble phosphorus was the highest with one per cent hydrochloric acid pretreatment. Potter and Benton [1916] used $N/5$ HCl for the purpose. Williams [1937] and Dean [1938] leached the soil with normal ammonium acetate and semi-normal sodium acetate respectively as a preliminary to soda extraction. In many of the neutral and calcareous soils such treatments were found to cause a large increase in the amounts of sodium hydroxide-soluble phosphorus and the effect increased significantly with $p$H values of soils.

In adopting a procedure where fractionation of the soil phosphorus is aimed at, the pretreating agent should effect complete removal of the exchangeable bases without dissolving phosphorus, organic or inorganic, which would come under other categories. To this purpose the dilute mineral acids do not answer well. Hydrochloric acid, for example, dissolves appreciable amounts of iron phosphates and in some cases organic phosphorus as well. Dilute acetic acid, on the other hand, is known to dissolve only the readily available phosphorus of the soil in addition to the removal of exchangeable bases. Its use, therefore, in a scheme of fractionation serves the double purpose of removing the exchangeable bases and of getting the available phosphorus fraction. On trial it was found that $N/2$ acetic acid dissolved the calcium phosphates almost fully but the phosphates of iron and aluminium were only slightly soluble. Moreover, determinations of organic phosphorus in the acetic acid extracts of about two dozens of organic soils showed that the amount of organic phosphorus dissolved by this reagent was in all cases negligible. A study of the comparative effectiveness of sodium acetate (used by Dean) and acetic acid as pretreating agents also showed that acetic acid pretreatment rendered more phosphorus alkali-soluble than did sodium acetate [Ghani, 1938].

## Alkali extraction

Gortner [1916] demonstrated that there might exist wide differences between the solvent action of different alkalies or different concentrations of the same alkali upon the organic matter of the soil. Schollenberger[1918], from a comparison of the solvent action of the hydroxides of alkali metals and ammonia, showed that at the quarter normal concentration the fixed alkalies extracted more total phosphorus than did normal ammonia but about the same amount of organic phosphorus. In all cases the quarter normal solution dissolved more phosphorus than the normal solution. Sodium carbonate extracted less phosphorus than sodium hydroxide and potassium hydroxide. Williams [1937] found that even the weakest concentrations of sodium hydroxide extracted the greater part of the phosphorus from the soil and that with increasing strength of alkali the amount extracted was constant or showed a slight tendency to increase. This was specially true when the exchangeable calcium was removed by ammonium acetate pretreatment. These evidences would indicate that quarter normal alkali can be used effectively for extracting the alkali-soluble phosphorus of the soil. This also reduces the possibility of the hydrolysis of the organic phosphorus compounds by a stronger alkali. The solvent action of sodium carbonate and sodium hydroxide is compared below, the extraction being done by Dean's procedure.

### *Sodium carbonate and sodium hydroxide extraction*

Ten grammes of acetic acid pretreated soil were placed in a beaker containing 100 c.c. of $N/4$ sodium carbonate solution and digested overnight on a water-bath. The beaker was covered with a clock glass to reduce evaporation. The suspension was next washed into a 500 c.c. measuring flask, made to volume and then allowed to stand for 24 hours. Inorganic and organic

phosphorus in the extract were determined on an aliquot of the supernatant liquid by the method of Ghani [1942]. The extraction with sodium hydroxide was done exactly in the same way except that 5 gm. of soil were taken instead of 10 gm. The results for five soils are shown in Table I.

TABLE I

*Sodium carbonate and sodium hydroxide soluble phosphorus*

(Mg. $P_2O_5$ per 100 gm. of soil)

| Soil | A 1441 Broad balk head land | A 1442 Woburn | A 1443 Bangor | A 3338 Broadbalk wilderness | A 2865 King's Lynn |
|---|---|---|---|---|---|
| Inorganic— | | | | | |
| $Na_2CO_3$ . . . | 39 | 27 | 65 | 26 | 20 |
| NaOH . . . | 62 | 41 | 160 | 40 | 40 |
| Organic— | | | | | |
| $Na_2CO_3$ . . . | 33 | 19 | 50 | 18 | 16 |
| NaOH . . . . | 64 | 33 | 160 | 56 | 32 |
| Total— | | | | | |
| $Na_2CO_3$ . . . | 72 | 46 | 115 | 44 | 36 |
| NaOH . . . . | 126 | 74 | 320 | 96 | 72 |

It will be seen from the above table that sodium carbonate extracts much less phosphorus than sodium hydroxide. This is true for both the organic and inorganic fractions. The difference was supposed to be due to the different soil-solvent ratios adopted in the two extractions and hence the effect of soil-solvent ratio on the amount of alkali-soluble phosphorus was next investigated.

## SOIL-SOLVENT RATIO

Fraps [1911] found that phosphorus extracted by $N/5$ nitric acid and 4 per cent ammonia decreased as the quantity of soil used per 100 c.c. of the solvents increased. Schollenberger [1918] working with 4 per cent ammonia showed that soil-solvent ratio had no appreciable effect on the total amount of phosphorus extracted.

0·5, 1, 2, 5 and 10 gm. of soil were extracted with 100 c.c. of $N/4$ sodium carbonate according to the method already described and phosphorus both organic and inorganic determined in the extracts. The results are shown in Table II.

TABLE II

*Soil-solvent ratio in sodium carbonate extraction*

(Mg. $P_2O_5$ per 100 gm. of soil)

| Soil-solvent ratio | 1/10 | 1/20 | 1/50 | 1/100 | 1/200 |
|---|---|---|---|---|---|
| A 1441—Rothamsted | | | | | |
| Inorganic . . | 39 | 52 | 88 | 76 | 66 |
| Organic . . | 33 | 36 | 37 | 54 | 84 |
| Total . | 72 | 88 | 125 | 130 | 150 |
| A 3328—Carbello | | | | | |
| Inorganic . . | 30 | 54 | 78 | 82 | 90 |
| Organic . . | 50 | 56 | 92 | 88 | 88 |
| Total . | 80 | 110 | 170 | 170 | 178 |
| A 3457—Saxmundham | | | | | |
| Inorganic . . | 27 | 37 | 45 | 51 | 42 |
| Organic . . | 11 | 7 | 20 | 29 | 38 |
| Total . | 38 | 44 | 65 | 80 | 80 |

The results show that the amount of phosphorus extracted increases as the soil-solvent ratio decreases. This observation holds true for the total, organic and inorganic phosphorus in the three soils studied, except that with soils No. 1441 and 3457, the inorganic fraction shows a tendency to decrease if less than 1 gm. of soil is used per 100 c.c. of the solvent. This discrepancy may, in all probability, be due to the sampling error involved in weighing out 0·5 gm. of soil. It will be noticed, however, that the increase in alkali soluble phosphorus is relatively small if the soil-solvent ratio is less than 1 : 100. This may, therefore, be taken as the suitable ratio in alkali extraction of soils.

For comparison, the sodium hydroxide soluble phosphorus of the soils was determined using 1/100 and 1/20 ratios. The results are given in Table III.

TABLE III

*Soil-solvent ratio in NaOH extraction*

(Mg. $P_2O_5$ per 100 gm. of soil)

| Ratio | 1/20 | 1/100 |
|---|---|---|
| A 1441— | | |
| Inorganic . . . . . . . . . | 62 | 80 |
| Organic . . . . . . . . . | 64 | 60 |
| Total . | 126 | 140 |
| A 3328— | | |
| Inorganic . . . . . . . . . | 96 | 100 |
| Organic . . . . . . . . . | 140 | 150 |
| Total . | 236 | 250 |
| A 3457— | | |
| Inorganic . . . . . . . . . | 41 | 55 |
| Organic . . . . . . . . . | 19 | 40 |
| Total . | 60 | 95 |

A comparison of Tables II and III shows that sodium hydroxide-soluble phosphorus, both organic and inorganic, at the same soil-solvent ratios are in all cases greater than the corresponding values obtained with sodium carbonate. This indicates that sodium carbonate does not completely extract the whole of the phosphorus that is supposed to fall in the alkali soluble category.

## TEMPERATURE OF EXTRACTION

In the earlier works of Fraps [1911], Potter and Snyder [1918] and Schollenberger [1918] the alkali extraction was done at room temperature by shaking for a period of time arbitrarily chosen. The recent workers, however, resorted to hot extraction. Williams [1937] extracted the soil with boiling sodium hydroxide solution by keeping the mixture in gentle ebullition on a hot plate for $2\frac{1}{2}$ to 3 hours. Dean [1938] digested the soil with alkali at 95°C. overnight. These conditions were all adopted arbitrarily and nothing is known about the effect of temperature and time of extraction upon the amount of phosphorus extracted and on possible hydrolysis of the organic phosphorus compounds during the extraction. The author [Ghani, 1942] has already reported data to show that hydrolysis of organic phosphorus takes place during bromine oxidation of the alkali extract at the boiling temperature.

To test the above points, extraction with sodium hydroxide was done in the following ways :—

1. At room temperature by shaking for different periods of time, viz. 2, 4, 8, 24 and 48 hours.
2. At 40°C. by immersing the mixture in a water-bath kept at 40°C. for different periods of time, viz. 1, 2, 4, 8 and 16 hours.
3. At 95°-100°C. in a water-bath for different periods of time, viz. 4, 8, 16, 32 and 48 hours.

The results are shown in Tables IV, V and VI.

TABLE IV

*Alkali extraction at room temperature*

(Mg. $P_2O_5$ per 100 gm. of soil)

| | 2 hours | 4 hours | 8 hours | 24 hours | 48 hours |
|---|---|---|---|---|---|
| Inorganic— | | | | | |
| A 1441 . . . . | 45 | 48 | 49 | 51 | 52 |
| A 3328 . . . . | 64 | 62 | 66 | 75 | 71 |
| A 3457 . . . . | 31 | 28 | 32 | 39 | 31 |
| Organic— | | | | | |
| A 1441 . . . . | 57 | 57 | 52 | 69 | 70 |
| A 3328 . . . . | 136 | 153 | 139 | 115 | 139 |
| A 3457 . . . . | 24 | 22 | 18 | 16 | 24 |
| Total— | | | | | |
| A 1441 . . . . | 102 | 105 | 102 | 120 | 122 |
| A 3328 . . . . | 200 | 215 | 205 | 190 | 210 |
| A 3457 . . . . | 55 | 50 | 50 | 55 | 55 |

TABLE V

*Alkali extraction at 40°C.*

(Mg. $P_2O_5$ per 100 gm. of soil)

| | 1 hour | 2 hours | 4 hours | 8 hours | 16 hours |
|---|---|---|---|---|---|
| Inorganic— | | | | | |
| A 1441 . . . | 48 | 54 | 56 | 53 | 58 |
| A 3328 . . . | 65 | 68 | 70 | 74 | 75 |
| A 3457 . . . | 30 | 37 | 37 | 32 | 36 |
| Organic— | | | | | |
| A 1441 . . . | 62 | 58 | 59 | 67 | 67 |
| A 3328 . . . | 145 | 132 | 130 | 146 | 145 |
| A 3457 . . . . | 28 | 23 | 25 | 26 | 24 |
| Total— | | | | | |
| A 1441 . . . | 110 | 112 | 115 | 120 | 125 |
| A 3328 . . . | 210 | 200 | 200 | 220 | 220 |
| A 3457 . . . | 58 | 60 | 62 | 58 | 60 |

TABLE VI

*Alkali extraction at 95°-100°C.*

(Mg. $P_2O_5$ per 100 gm. of soil)

| | 4 hours | 8 hours | 16 hours | 32 hours | 48 hours |
|---|---|---|---|---|---|
| Inorganic— | | | | | |
| A 1441 . . . . | 78 | 78 | 79 | 100 | 101 |
| A 3328 . . . . | 92 | 98 | 100 | 115 | 143 |
| A 3457 . . . . | 44 | 44 | 52 | 69 | 74 |
| Organic— | | | | | |
| A 1441 . . . . | 52 | 57 | 66 | 45 | 46 |
| A 3328 . . . . | 128 | 125 | 145 | 125 | 99 |
| A 3457 . . . . | 20 | 31 | 40 | 21 | 16 |
| Total— | | | | | |
| A 1441 . . . . | 130 | 135 | 145 | 145 | 147 |
| A 3328 . . . . | 220 | 222 | 245 | 240 | 242 |
| A 3457 . . . . | 64 | 75 | 92 | 90 | 90 |

From Table IV it is seen that the time of shaking at room temperature has practically no effect on the alkali-soluble phosphorus fraction. All the three quantities remain nearly constant, with a slight tendency to increase with time. At 40°C. also (Table V) no significant variation in the results is obtained, both organic and inorganic phosphorus remaining at a fairly constant level irrespective of the duration of extraction. By comparing Tables IV and V, it will further be observed that the fractions extracted at 40°C. are not higher than those obtained at the room temperature, suggesting neither a greater solvent action nor hydrolysis at 40°C. The results of hot extraction presented in Table VI, reveal completely different things. Here the inorganic phosphorus shows a slight tendency to increase to the 16 hours digestion period after which there is a rapid increase. On the other hand, the organic phosphorus at first increases similarly to that period of digestion and then falls down rapidly. This contrasting behaviour of the two fractions can be explained only as follows :— The amount of organic and inorganic and hence the total phosphorus dissolved in the alkali increases with time but hydrolysis of the organic phosphorus takes place at the same time. After about 16 hours, extraction is nearly complete but decomposition proceeds very rapidly thereby reducing the amounts of organic phosphorus in

he extract and increasing the inorganic counterpart. That the total phosphorus did not change after 16 hours shows that extraction was complete by that time. Moreover, a comparison of the 48 hours extraction figures in Tables IV and VI will show that the inorganic phosphorus was almost doubled in all the three soils by raising the temperature of extraction to 100°C. whereas the organic phosphorus was reduced by about one-third its value. This clearly shows that decomposition of organic phosphorus undoubtedly takes place during extraction at a high temperature. The change in inorganic and organic phosphorus is shown graphically in Fig. 1.

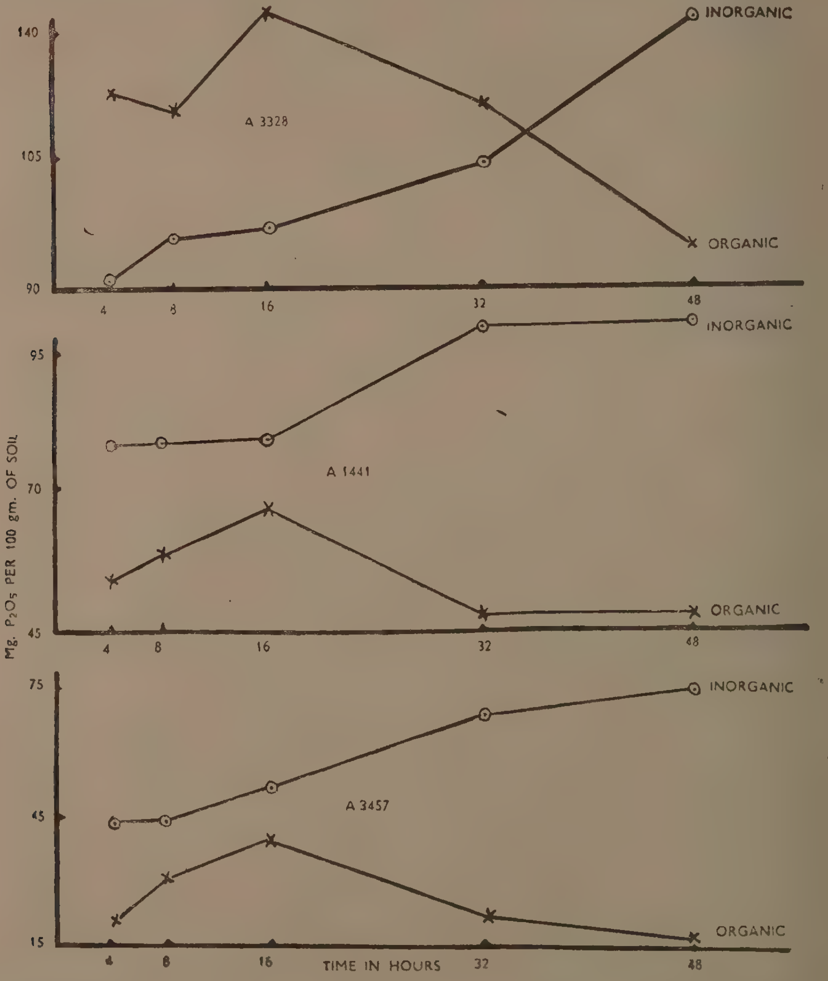



FIG. 1. Showing the change in inorganic and organic phosphorus with time at alkali extraction at 100°C.

From what has been stated above it is evident that hot extraction method is completely unsuitable for the purpose of fractionation of the soil phosphorus as it prevents any true distinction being made between the organic and inorganic phosphorus dissolved by alkali. The alkali extraction should, therefore, be carried out at the room temperature by shaking and extraction should be repeated, if necessary, with the residual soil. It has been shown by various workers that extraction of the soluble constituents is not completed by one treatment and that sometimes five or more treatments are necessary.

## Repeated extraction of the soil

In repeated extraction, it is advisable to remove one extract completely before proceeding to the next. This is particularly important when different solvents are to be used in succession. By the ordinary method of filtration an unknown volume of water (and hence an unknown amount of phosphorus) retained by the soil and the filter paper goes over to the next extract, thereby reducing the concentration of the latter and also adding some phosphorus to it. Secondly, in a long series of successive extractions a filter paper will be each time added to the bulk of the soil causing great inconvenience in the filtration which in itself is a tedious process. To overcome these difficulties and inaccuracies and also to ensure complete filtration, a Pasteur-Chamberland candle was used in an apparatus similar to that designed by Dreyspring and Heinz [1935].

## The design of the apparatus

The apparatus is shown in Fig. 2. A Pasteur-Chamberland candle (L3

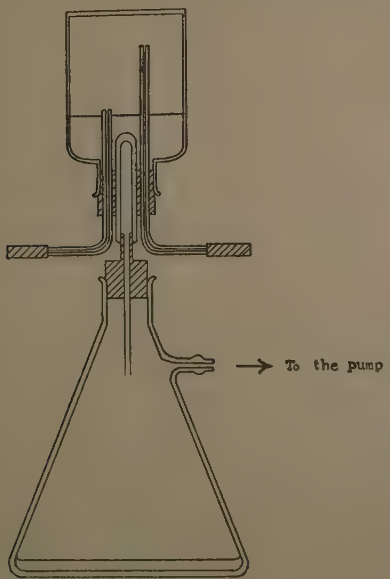



FIG. 2. Filtering apparatus for repeated extraction of the soil

7·5 cm.) is fitted into a rubber bung which fits tightly into a 250 c.c. bottle with the candle inside the bottle. Two heavy-walled capillary glass tubes are also inserted into the stopper, their outer ends being bent at right angles and fitted with rubber tubes so that they can be closed by inserting two small pieces of glass rod. The length of the tubes inside the bottle are adjusted so as to keep their ends above the surface of 100 c.c. of liquid both when the bottle is in an erect and in an inverted position. The bottle is supported in an inverted position by fixing the candle on to a glass tube passing through a bung into a filter flask, the lower end of the tube being below the side tube of the flask so that no filtrate is drawn out by suction.

### Procedure for repeated extraction of soil

One gramme of soil and 100 c.c. of the solvent are placed into the bottle which is then closed with the rubber stopper containing the porous candle. Both the capillaries are then closed with pieces of glass rods and the bottle shaken in a mechanical shaker for a period of four hours. After the shaking is over the bottle is fitted in the filter flask in an inverted position and allowed to stand for sometime so that the suspended soil particles may settle

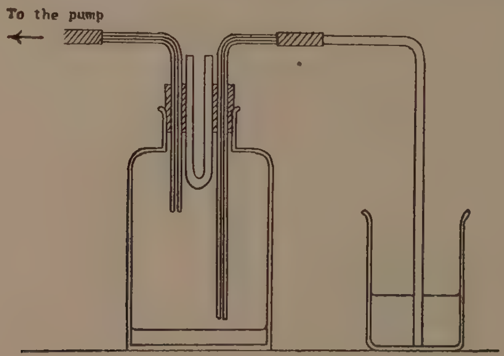



**Fig. 3. Apparatus in an erect position while the solvent is being drawn in**

down. This prevents the pores of the candle from being clogged by suspended matter during the suction. When the particles have settled down, suction is applied. In the case of highly organic soils filtration of the alkali extract is very slow and is allowed to go on overnight. When the filtration is over, the bottle is disconnected from the filter flask and connected to the pump through one of the capillary tubes, the other one being dipped through a bent tube into a measuring cylinder or beaker containing a known volume of the desired solvent. The solvent is thus drawn into the bottle (Fig. 3). This procedure is used because if the stopper is displaced from the bottle, the soil is disturbed and it becomes difficult to wash all of it quantitatively into the bottle. The extraction is then repeated with the same or any other solvent as desired.

### Acid extraction after alkali

After the soil is thus extracted with acetic acid and sodium hydroxide, presumably most of the apatites of the soil are left unaffected in the residue. To remove this fraction, the residual soil from the alkali extraction was in the same way repeatedly extracted with $2N$ sulphuric acid. The phosphorus still left in the soil after these combined acid and alkali extractions would definitely represent an inert combination and may, as suggested by Marshall [1935], be present as an integral part of the clay lattice.

### The phosphorus fractions

In the light of the above study, the soil phosphorus may be divided into five groups as described below. The chemical nature of the groups will be fully dealt with in part II of this series.

1. Acetic acid-soluble. Mono-,di- and tri-calcium phosphates. This probably constitutes the fraction that is easily available to plants.
2. Alkali-soluble inorganic. Iron and aluminium phosphates. This probably constitutes the fraction that is definitely available to plants.
3. Alkali-soluble organic. Total organic phosphorus of the soil (nucleic acid, phytin, leoithin, etc.). This is available to plant only through decomposition.
4. Sulphuric acid-soluble. Phosphates of apatite type. This is probably unavailable to plant.
5. Insoluble. Presumably this forms an integral part of the clay complex and is inert so far as phosphate nutrition of the plant is concerned.

### The modified method of fractionation

The procedure of fractionation finally adopted may be described as follows :—

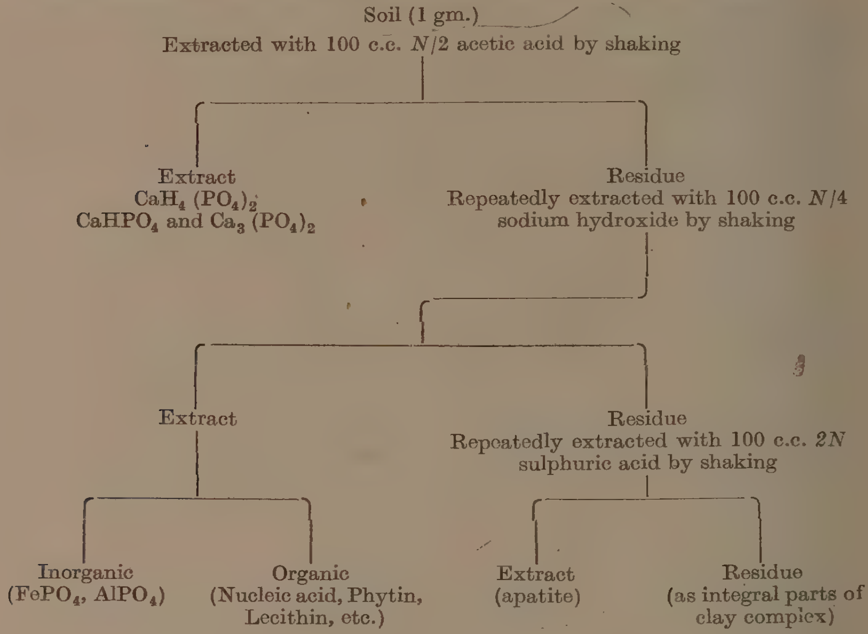
One gramme sample of the soil is introduced into the filtering apparatus (described before) and shaken continuously with 100 c.c. of $N/2$ acetic acid for two hours in a mechanical shaker. The extract is filtered immediately after shaking and acetic acid soluble phosphorus determined on a suitable aliquot of the extract.

The residual soil in the apparatus is then similarly shaken with 100 c.c. of $N/4$ sodium hydroxide and extraction repeated until the phosphorus extracted by alkali is very low or nil. The inorganic and organic phosphorus in the extracts are determined by the method of Ghani [1942]. To get the phosphorus fraction of the soil, the fractions obtained in the several extracts are summed up.

The residual soil is again repeatedly extracted by shaking with 100 c.c. of $2N$ sulphuric acid and phosphorus determined on an aliquot of the extract.

To get the insoluble fraction, the sum of the phosphorus dissolved by acetic acid, sodium hydroxide and sulphuric acid is subtracted from the total soil phosphorus determined separately by the A. O. A. C. gravimetric method.

The outline of the method is presented below diagrammatically.




## Application of the proposed method of fractionation to eight soils of different types

Eight soils of different types and having different manurial history were selected for analysis according to the procedure developed and described before. Their essential characters are summarized below.

## Description of soils

*Acid mineral soils*

A 1441. A heavy loam from the edge of Broadbalk continuous wheat Rothamsted. Unlike the soils of the old experimental plots, this soil is acid having formed part of an old grass headland which was ploughed up long after the wheat experiments began. This sample was used in A. E. A. Co-operative Experiments on soil analysis.

*Neutral mineral soils*

A 3457. A calcareous clay loam from calcareous boulder clay at the Sexmundham Experimental Farm, East Suffolk. Crops on this land responded well to phosphate.

A 2328. A heavy loam from Broadbalk continuous wheat plot 2 B, receiving 14 tons of farm-yard manure per acre annually since 1843.

*Acid mineral soil ploughed out from long leys*:

A 3328. An acid loam from Carbello, Cranberry, Ayrshire, derived from drift. Taken from a Swede plot in which high soluble slag increased the yield from 2 to 25 tons per acre. The land for Swedes was ploughed out after several years in ley.

*Organic soils*

A 3769. An acid peaty loam from Flatterton, Inverkip, Refrewshire taken from a Swede plot in which basic slag increased the yield from three to 24 tons per acre.

A 3246-7. A heavy acid fen soil from Whittlesea, Peterborough. Taken from 27-plot NPK experiments in which superphosphate gave a significant increase in yield. This soil was chosen because its citric acid soluble $P_2O_5$ (62 mg. per cent) was greatly in excess of acetic and soluble $P_2O_5$ (4 mg. per cent).

A 3560-1. A heavy acid fen soil from Littleport Farm, from a 27-plot NPK potato experiment in which superphosphate gave a significant increase in yield.

## Results and discussion

The results of fractionation showing the analyses of the individual extracts are shown in Table VII. In Table VIII are given the summarized results obtained by the summation of the repeated extracts with each solvent. For convenience of study the data are expressed both as per cent of the soil and as per cent of the total soil phosphorus.

From the data in Table VII it is seen that both organic and inorganic phosphorus fell off rapidly in successive extracts and that five extractions were necessary to bring down the sodium hydroxide soluble phosphorus to a low quantity. Schollenberger [1918] showed that in successive extracts of soils with 4 per cent ammonia the soluble phosphorus was quite low in the fourth extract, it was about 2·3 mg. $P_2O_5$ per 100 gm. of soil. It will also be seen that no organic phosphorus was dissolved by the acetic acid and sulphuric acid before and after the alkali extraction respectively.

Table VIII shows the relative proportion of the various phosphorus fractions in the different types of soil under study. The four fractions determined by combined acetic acid, alkali and sulphuric acid extraction account for at least 95 per cent of the total phosphorus in five of the eight soils, and for over 80 per cent in all of the soils. Considering the inevitable errors ir adding up so many analyses, it would appear that almost all of the soil phosphorus is soluble under these conditions of extraction.

The acetic acid soluble fractions were very small in all soils, except those from manurial plots at Woburn, Rothamsted and Saxmundham (A 2242, A 3457 and A 2328). It is noteworthy that the Rothamsted Broadbalk plot which receive farmyard manure annually was outstandingly rich in readily available inorganic phosphorus. On the other hand, the acid organic soils and the grass headland soil from Rothamsted showed deficiency in this form of phosphorus.

# TABLE VII

*Phosphorus fractions in repeated extracts*

(Mg. $P_2O_5$ per 100 gm. of soil)

| — | A 1441 | | A 2242 | | A 3457 | | A 2328 | | A 3328 | | A 3769 | | A 3246-7 | | A 3560-1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inorg. | Org. | Inorg. | Org. | Inorg. | Org. | Inorg. | Org. | Inorg. | Org. | Inorg. | Org. | Inorg. | Org. | Inorg. | Org. |
| N/2 acetic acid . | 2·3 | ... | 9·8 | ... | 10·6 | ... | 59·2 | ... | 1·6 | ... | 1·3 | ... | 3·4 | ... | 9·2 | ... |
| N/4 sodium hydroxide— | | | | | | | | | | | | | | | | |
| 1 . . . | 49·0 | 54·0 | 89·0 | 34·0 | 25·5 | 25·0 | 87·5 | 35·0 | 73·7 | 124·0 | 92·0 | 215·0 | 247·5 | 80·0 | 66·2 | 54·0 |
| 2 . . . | 7·0 | 9·5 | 12·0 | 3·2 | 3·6 | 6·1 | 10·5 | 5·0 | 8·5 | 11·5 | 8·2 | 20·0 | 28·5 | 17·0 | 13·0 | 17·0 |
| 3 . . . | 2·0 | 3·2 | 1·6 | 1·8 | 0·4 | 2·8 | 3·8 | 1·7 | 2·3 | 2·2 | 2·3 | 5·2 | 11·0 | 8·7 | 9·0 | 5·2 |
| 4 . . . | 2·2 | 0·9 | 3·4 | 2·3 | 0·3 | 1·6 | 3·6 | 2·5 | 0·7 | 1·8 | 1·7 | 1·5 | 11·1 | 1·3 | 2·0 | 5·4 |
| 5 . . . | 2·1 | 0·9 | 0·3 | 0·6 | 0·5 | 1·7 | 1·0 | 1·0 | 0 | 0 | 0·2 | 1·8 | 3·2 | 0·7 | 0·2 | 2·2 |
| Total . | 62·3 | 68·5 | 106·3 | 41·9 | 30·3 | 37·2 | 106·4 | 45·2 | 85·2 | 139·5 | 104·4 | 243·5 | 301·3 | 107·7 | 90·4 | 83·8 |
| 2N sulphuric acid | | | | | | | | | | | | | | | | |
| 1 . . . | 14·0 | ... | 9·6 | ... | 9·7 | ... | 12·6 | ... | 7·8 | ... | 29·6 | ... | 43·2 | ... | 28·0 | ... |
| 2 . . . | 4·4 | ... | 5·2 | ... | 6·2 | ... | 6·8 | ... | 5·1 | ... | 8·0 | ... | 16·0 | ... | 10·2 | ... |
| Total . | 18·4 | ... | 14·8 | ... | 15·9 | ... | 19·4 | ... | 12·9 | ... | 37·6 | ... | 59·2 | ... | 38·2 | ... |

TABLE VIII

*Fractions of soil phosphorus*

(Mg. $P_2O_5$ per 100 gm. of soil)

| —— | Acetic acid soluble | Inorg. alkali soluble | Org. | $H_2SO_4$ soluble | Insoluble (by difference) | Total |
|---|---|---|---|---|---|---|
| Acid mineral— | | | | | | |
| A 1441 Roth. | 2 | 62 | 68 | 19 | 19 | 170 |
| A 2242 Wob. | 10 | 106 | 42 | 15 | 41 | 214 |
| Neutral mineral | | | | | | |
| A 3457 Sax. | 11 | 30 | 37 | 16 | 5 | 99 |
| A 2328 Broad. | 59 | 106 | 45 | 19 | 39 | 268 |
| Acid mineral ploughed after long ley— | | | | | | |
| A 3328 Carb. | 2 | 85 | 140 | 13 | —7 | 233 |
| Peaty soil— | | | | | | |
| A 3769 Flat. | 1 | 104 | 243 | 38 | —7 | 379 |
| A 3246-7 Pet. | 3 | 301 | 108 | 59 | —5 | 466 |
| A 3560-1 Lit. | 9 | 90 | 84 | 38 | 14 | 235 |
| Fractions as percentage of total $P_2O_5$ | | | | | | |
| A 1441 . | 1 | 36 | 40 | 11 | 11 | .. |
| A 2242 . | 5 | 50 | 20 | 7 | 19 | .. |
| A 3457 . | 11 | 30 | 37 | 16 | 5 | .. |
| A 2328 . | 22 | 40 | 17 | 7 | 15 | .. |
| A 3328 . | 1 | 36 | 60 | 6 | —3 | .. |
| A 3769 . | 0 | 27 | 64 | 10 | —2 | .. |
| A 3246-7 . | 1 | 65 | 23 | 13 | —1 | .. |
| A 3560-1 . | 4 | 38 | 36 | 16 | 6 | .. |

The alkali-soluble inorganic phosphorus which is presumably mainly iron phosphate, ranged from 27 per cent to 65 per cent of the total and proved to be the highest single fraction in four of the soils. The highest value was

from the Peterborough soil (A 3246-7) which was included in this series because it gave unusually high citric-soluble phosphorus in relation to its acetic-soluble phosphorus. In spite of the fact that the soil contains 17 per cent carbon, it is interesting to find the inorganic phosphorus of the alkali extract almost three times as great as the organic phosphorus. In the most highly organic soil of the series (A 3560-1) the organic and inorganic forms in the alkali extracts were about equal. The two Scottish soils (A 3328 and A 3769) from basic slag experiments on soils ploughed out for Swedes from five or more years under grass showed very similar analyses, with the highest proportion (about two-thirds) of their total phosphorus in the organic form. This would suggest that a considerable fraction of the phosphorus in such grassland soils remains in a very stable and inert form. Although nitrogen would be liberated during the cultivation for Swedes it would appear that little of the organic phosphorus becomes available, since the Swede crops were complete failures except where basic slag was given. It was observed in these field experiments that the residual effects of the basic slag on oats and hay were very small in spite of the very large response in the Swede crop. This has been taken to mean that the oats grown have access to phosphorus which the Swedes cannot utilize. It is, however, possible that some of the organic phosphorus is broken down during the year after ploughing in sufficient amounts to meet the lower requirements of these crops.

The organic phosphorus forms a low portion of the whole in the two soils (Broadbalk and Woburn) which have been cropped for half a century or more with continuous cereals (wheat and barley respectively). On the other hand, the second sample from Broadbalk field, which has a moderate proportion of organic phosphorus, is an acid soil, ploughed out from a grass head land some long time after the experiments on wheat were commenced. These results suggest that the organic phosphorus is built up largely by grass and that it is relatively stable under acid conditions. It is also notable that the Broadbalk farmyard manure plot has a low proportion of organic phosphorus. Apparently the organic phosphorus of farmyard manure is mineralized fairly quickly at least in neutral soils. This has already been pointed out by the author in an earlier communication [Ghani, 1941].

The sulphuric acid-soluble fractions are much lower than the alkali-soluble inorganic fractions, suggesting that the bulk of the phosphorus in most arable soils accumulates as iron phosphates rather than as an apatite.

## Summary

The method of fractionation of soil phosphorus by combined acid and alkali extraction as proposed by Dean has been critically examined.

$N/2$ acetic acid has been suggested as a pre-treating agent for the removal of exchangeable bases before alkali extraction and as a solvent for the readily available phosphorus.

Sodium hydroxide extracts more phosphorus than sodium carbonate at the same con entration and at the same soil-solvent ratio.

The amount of phosphorus extracted by alkali increases as the soil-solvent ratio decreases. The increase is relatively small when the ratio is lower than 1 : 100.

Alkali extraction at 100°C. dissolved more phosphorus than at room temperature or at 40°C. but at 100°C. the organic phosphorus compounds are partly decomposed.

Several extractions are necessary to dissolve the whole of the soluble phosphorus at the room temperature. A Pasteur-Chamberland porous candle has been used in the design of an apparatus for repeated extraction of soil.

The use of $2N$ sulphuric acid after alkali has been suggested for the removal of the apatite fraction.

The modified method has been applied to eight soils of different types and the phosphorus fractions interpreted in the light of their past manurial history.


### Acknowledgements

The work reported was carried out at the Rothamsted Experimental Station and formed part of a thesis for the Ph.D. degree of the London University. The author wishes to express his thanks to Sir John Russell for permission to work at Rothamsted and to Dr E. M. Crowther for the great interest he took in it and the valuable suggestion he gave throughout. Thanks are also due to Mr R. G. Warren for much help and criticism.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# THE WILD RICE PROBLEM IN THE CENTRAL PROVINCES AND ITS SOLUTION

BY

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(Received for publication on 23 March 1942)

(With Plate I)

RICE is by far the most important food crop in the Central Provinces and Berar, occupying 59 lakhs of acres out of the 245 lakhs devoted to crops. The old Chhattisgarh division, comprising the districts of Raipur, Drug and Bilaspur, contains more than 62 per cent of the total rice area in the province. The prevalence of wild rice (*Karga*) as a weed in the *biasi* paddy fields of Chhattisgarh constitutes a serious economic problem. During the period of vegetative growth wild rice is indistinguishable from most of the cultivated varieties and cannot, therefore, be weeded out in time to allow the legitimate crop to tiller and fill in the gaps. In badly infested fields the percentage of wild rice is sometimes as high as 30, but even if the average infestation be taken to be only 3 per cent the loss it causes over 37 lakhs of acres of *biasi* paddy amounts to more than 22 lakhs of rupees every year. Reduction of this loss has been one of the main objects of breeding work in rice since the year 1928 and it has now been attained by the production of early, medium and late ripening purple-leaved hybrids which give good yield. The seedlings of these hybrids (Plate I) are entirely purple and can thus be very easily distinguished from the green *Karga* seedlings. The results of these experiments are summarized below.

## Review of literature

An estimate of the loss due to the occurrence of wild rice was made in 1930 by the Director of Agriculture, Central Provinces and Berar, Mr Plymen, who observes that the percentage of wild rice is at times as high as 30 per cent of the standing crop on a cultivator's field. Roy [1921] working in the Central Provinces reports that in the Chhattisgarh tract the amount of loss due to the occurrence of wild rice is sometimes said to be so great as to reduce the out-turn of rice by 50 per cent. He suggests that the best method to get rid of wild forms is to grow coloured rice (*Nagkesar*) or adopt transplantation. Salimath [1921] found that in various parts of Belgaon district of the Bombay presidency, the loss due to the occurrence of wild rice varies from 5 to 25 per cent while other places have been found where up to 30 per cent of the grain is lost either before or during reaping. Bhalerao [1930] suggests that the source of infection through soil, irrigation water and seed should be guarded against to obtain the best results.

## Experimental results

The incidence of wild rice in *biasi* paddy fields was studied during 1940 and 1941 in 43 villages in Raipur, Drug and Bilaspur districts. In each

FIG. 1
Seedling one month old

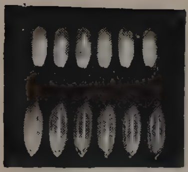

FIG. 2
Cross No. 1
(No. 17 × *Nagkesar*)
Early

FIG. 3
Cross No. 2
(*Nagkesar* × *Bhondu*)
Medium ripening

FIG. 4
Cross No. 5
(*Nagkesar* × *Luchai*)
Late

Rice hybrids for fields infested with wild rice

village, ten fields were taken at random and the population of wild and cultivated rice plants was recorded, at the flowering stage during the months of September and October, in three quadrates per field. The size of the quadrate was 4 ft. 8 in. square or 1/2000th of an acre. The results are given in Table I.

TABLE I

*Average percentage of wild rice in* biasi *paddy fields*

| Tahsil | Village | Average percentage of wild rice | Tahsil | Village | Average percentage of wild rice |
|---|---|---|---|---|---|
| Raipur | Dongitarai | 41 | Bilaspur | Badri | 17 |
| | Piprod | 42 | | Sakri | 17 |
| | Chipridih | 54 | | Barpali | 18 |
| | Patewa | 55 | | Hafa | 18 |
| | | | | Sarseni | 20 |
| Balodabazar | Sonpuri | 9 | | Motia | 21 |
| | Balodabazar | 14 | | Jalso | 25 |
| | Sukla | 16 | | Khaira | 28 |
| | Bharsela | 17 | | Semartal | 35 |
| | | | | Koni | 36 |
| Dhamtari | Deoni | 6 | | Gatauri | 37 |
| | Gokulpur | 7 | | Sendri | 37 |
| | Karetha | 7 | | | |
| | | | Janjgir | Andi | 4 |
| Mahasamund | Atharagudi | 6 | | Charoda | 4 |
| | Chinoordih | 11 | | | |
| | Lohroad | 12 | Katghora | Solara | 5 |
| | Nawapara | 12 | | Maheshpur | 6 |
| | Chote Temri | 23 | | Bendarkona | 7 |
| | Bitangipali | 27 | | Kenadand | 8 |
| | Bhatori | 27 | | Chakomar | 9 |
| | Basna | 31 | | | |
| | | | Drug | Matwari | 44 |
| | | | | Janjgiri | 44 |
| | | | Bemetara | Chuchrungpur | 5 |
| | | | | Bahera | 6 |
| | | | | Basna | 7 |

The percentage occurrence of wild rice varies very widely from as low as 4 to as high as 55. Generally speaking, wild rice occurs more on the lighter soils than on the heavier ones.

A field-to-field study of the occurrence of wild rice was made in Jora village, adjoining Labhandi farm in Raipur district. In each of the 1,315 fields sown with rice, two quadrates (each 4 ft. 8 in. square) were taken at random and the number of plants of wild and cultivated rices in each quadrate recorded. The average percentage of wild rice for the entire village worked out to be three.

In a similar field-to-field study made in 1,843 paddy fields of Borsi village in Drug district and 480 fields of Darri village in Bilaspur district, the average percentage of wild rice for the entire village, in both the cases, was again found to be three. These observations were made in October when the crop was in ears and much of the wild rice had already been removed by weeding.

If the lowest estimate of loss due to the occurrence of wild rice is taken at only 3 per cent of the yield, the standard outturn at 661 lb. of cleaned rice per acre and the wholesale price of rice at Rs. 2-8 per md. of 82 lb., the loss in yield to the cultivators of Raipur, Drug and Bilaspur districts, where 37 lakhs of acres are under *biasi* paddy, amounts to 22 lakhs of rupees every year. The loss would be much more at the present high prices. To this have to be added the weeding charges for the removal of wild rice which at six annas per acre would amount to another 14 lakhs of rupees. The third weeding which is given at the flowering stage is only for the removal of wild rice.

Reduction of this loss has been one of the main objects of breeding work in rice since the year 1928. It has been stated that wild rice has a green or purple leaf-sheath like most of the cultivated varieties and so is indistinguishable from them and cannot be weeded out. It is recognized after the flowering stage by the presence of long stout awns, blackish grains and red kernels. On account of its characteristic nature of shedding the grains completely, its seed cannot be collected. It thus gets self sown and increases from year to year. The presence of wild rice in the field is a constant source of contamination and brings about a deterioration of the cultivated variety due to natural cross pollination. In an attempt to control the spread of wild rice the farmers sow varieties with green and dark purple leaf-sheath in alternate years or grow *Parewa*, a variety which has dark purple auricles to distinguish it from wild rice, but this variety, comparatively speaking, is a poor cropper.

An attempt was, therefore, made to combine the dark purple auricles of *Parewa* with the commercial variety *Budhiabako* and the high yielding *Bhondu*. The crosses were made by the writer in October 1928 at the Agricultural Research Institute, Nagpur, and the $F_1$, $F_2$ and $F_3$ generations studied in 1929 and succeeding years. Further details about this work will be found in another paper on 'Inheritance of Characters' to be published. Promising hybrids possessing the desired combination of characters were secured in the $F_4$ generation in 1932. The fixed hybrids in the $F_5$ and $F_6$ generations were tested for yield against the parents in Latin Square during 1933 and 1934 at Raipur and in randomized blocks in subsequent years. The results are summarized in Tables II and III.

TABLE II

*Yield of cross No. 116* (Bhondu × Parewa) *compared with the parents, Raipur*

| Strain | Mean yield in lb. per acre | | | | | |
|---|---|---|---|---|---|---|
| | 1933 | 1934 | 1935 | 1936 | 1937 | Average |
| Cross No. 116 | 3844 | 2846 | 3013 | 2905 | 3061 | 3134 |
| *Bhondu* | 3071 | 2543 | 2986 | 2683 | 2961 | 2849 |
| *Parewa* | 3332 | 2442 | 2450 | 2355 | 2478 | 2611 |

*Biasi*—a method of rice cultivation which consists of broadcasting the seed followed by ploughing to thin out the seedlings when they are a foot high

On an average of five years, Cross No. 116 (*Bhondu* × *Parewa*) has given 10 per cent higher yield than *Bhondu* (which was so far the most prolific variety) and 20 per cent higher yield than *Parewa*.

TABLE III

*Comparison of cross No. 19* (Budhiabako × Parewa) *with* Budhiabako

| Strain | Mean yield in lb. per acre | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Unmanured | | | | |
| | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | Average |
| Cross No. 19 . . . | 2829 | 2205 | 2932 | 1572 | 1497 | 1461 | 1323 | 1974 |
| *Budhiabako* . . . | 2453 | 2932 | 2527 | 1603 | 1411 | 1175 | 1375 | 1925 |

The average results of all the seven years show that Cross No. 19 is as good as the higher yielding parent *Budhiabako* and has the added advantage of being readily distinguished from wild rice.

These trials were simultaneously extended to Government farms at Chandkhuri, Drug and Bilaspur and finally the hybrids were tested on an extensive scale on the cultivators' holdings from 1937 onwards.

In trials now extending over nine years, cross No. 116 (*Bhondu* × *Parewa*) has proved to be the highest yielding strain in the province. Similarly, cross No. 19 (*Budhiabako* × *Parewa*) is the highest yielding strain among medium-fine varieties. Both of them possess dark-purple auricles which distinguish them from wild rice in the seedling stage. These hybrids are now under distribution from all the seed farms in Chhattisgarh and have become very popular. A description of the hybrid strains is given in Appendices A and B.

A more complete solution of the wild rice problem was attempted in 1934 when most of the improved rice strains were crossed with *Nagkesar*, a variety which possesses leaves and stem of purple colour by virtue of which it can be easily distinguished from wild rice. Unfortunately, the yield of *Nagkesar* is very low and its rice is generally red. The crosses of *Nagkesar* with No. 17 *Bhondu*, *Budhiabako*, *Gurmatia* and *Luchai* were raised in the $F_1$ generation in 1935 and the $F_2$ and $F_3$ generations studied in succeeding years. The study of the inheritance of economic characters in these crosses will form the subject of a separate paper. Early, medium and late ripening strains possessing purple leaves to distinguish them from wild rice in the seedling stage were secured in the $F_4$ generation in 1938 and they were tested for yield against the parents in randomized blocks. The results are summarized in Table IV.

TABLE IV

*Yield of purple-leaved hybrids compared with the parents, Raipur*

| Strain | Mean yield in lb. per acre (Unmanured) | | | | Remarks |
|---|---|---|---|---|---|
| | 1939 | *1940 | *1941 | Average | |
| *Early* | | | | | |
| Cross No. 1 (No. 17 × *Nagkesar*) | 1478 | 896 | 963 | 1112 | *General yields are low on account of inadequate rains |
| *Nungi* (No. 17) . . . | 1750 | 640 | 1056 | 1149 | |
| *Medium* | | | | | |
| Cross No. 2 (*Nagkesar* × *Bhondu*) | 1680 | 1388 | 1250 | 1439 | |
| *Bhondu* . . . . . | 2292 | 1310 | 1467 | 1690 | |
| *Late* | | | | | |
| Cross No. 5 (*Nagkesar* × *Luchai*) | 1690 | 1616 | 1350 | 1552 | |
| *Luchai* . . . . . | 1998 | 1476 | 1029 | 1501 | |
| *Nagkesar* (Medium) . . | ... | 1008 | 1071 | 1040 | |

These hybrids were simultaneously tested at the Government farms at Chandkhuri, Drug and Bilaspur and finally they were tried on an extensive scale on the cultivators' holdings in 1940 and 1941. The yields have been satisfactory and this year 16,000 lb. seed of the early, medium and late ripening purple-leaved hybrids has been supplied in 275 villages of Raipur, Drug and Bilaspur districts for multiplication. The advantages of growing these hybrids in fields infested with wild rice are so obvious that no further propaganda will be necessary to secure their natural spread. The seedlings of the hybrids are entirely purple (Plate I) and can thus be very easily distinguished from the green *Karga* seedlings. These hybrids are not expected to deteriorate by natural cross pollination with other green varieties as the purple leaf-blade colour is recessive to green and the first generation hybrids, which will have green leaves, will be weeded out along with wild rice plants. Practically the whole of the annual loss referred to above can now be prevented by growing these hybrids in fields infested with wild rice. A description of the hybrid strains is given in Appendices A and B.

ACKNOWLEDGEMENTS

This work formed part of the programme of the Central Provinces Rice Research Scheme which has been generously financed by the Imperial Council of Agricultural Research.

## Summary

The prevalence of wild rice (*Karga*) as a weed in the *biasi* paddy fields of Chhattisgarh constitutes a serious economic problem. During the period of vegetative growth wild rice is indistinguishable from most of the cultivated varieties and cannot, therefore, be weeded out in time to allow the legitimate crop to tiller and fill in the gaps. In badly infested fields the percentage of wild rice is sometimes as high as 30, but even if the average infestation be taken to be only 3 per cent the loss it causes over 37 lakhs of acres of *biasi* paddy amounts to more than 22 lakhs of rupees every year. Reduction of this loss has been one of the main objects of breeding work in rice since the year 1928 and it has now been attained by the production of early, medium and late ripening purple-leaved hybrids which give good yield. The seedlings of these hybrids are entirely purple and can thus be very easily distinguished from the green *Karga* seedlings. Practically the whole of the annual loss referred to above can now be prevented by growing these hybrids in fields infested with wild rice. A description of the hybrid strains has been given.


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## APPENDIX A

### *Rice hybrids for fields infested with wild rice*

*Cross No. 1* (*Nungi*—No. 17 × *Nagkesar*). A high yielding early strain suitable for unprotected high lying areas and unirrigated fields infested with wild rice. Seedlings entirely purple and very easily distinguishable from green *Karga* seedlings. Ripens in the 3rd week of October, (sowing time—middle of June). Average yield, 1939 to 1941, (unmanured) 1,100 lb. per acre.

*Cross No. 2* (*Nagkesar* × *Bhondu*). A medium ripening strain with leaves and stem of purple colour to distinguish it from wild rice. Suitable for all types of irrigated soils. Ripens in the 2nd week of November. Very good yielder. The paddy is reddish-brown and the rice is coarse and white. Average yield, 1939 to 1941, (unmanured) 1,450 lb. per acre.

*Cross No. 5* (*Nagkesar* × *Luchai*). A high yielding late strain with an erect habit of growth and comparatively free from lodging. Suitable for irrigated tracts and heavy soils or low lying areas infested with wild rice. Leaves—purple. Ripens in the 4th week of November. Average yield, 1939 to 1941, (unmanured) 1,550 lb. per acre.

*Cross No. 19* (*Budhiabako* × *Parewa*). This is the highest yielding strain among medium-fine varieties and is well suited for irrigated tracts. It has dark purple auricles to distinguish it from wild rice. It is late and is harvested in the 3rd week of November. The rice is translucent and is sold in the market under the trade name of *Hansa*. Average yield, 1937 to 1941, (unmanured) 1,750 lb. per acre. It has become very popular in Chhattisgarh under the name '*Kanthi Budhiabako*'.

*Cross No. 116* (*Bhondu* × *Parewa*). This is the highest yielding strain in the Province and is much liked by people who prefer bulk to quality. It ripens in the 2nd week of November and is suitable for all types of soils protected by irrigation. It has dark purple auricles to distinguish it from wild rice. The paddy is reddish brown and the rice is coarse and white suitable for the preparation of puffed and shredded rice. Average yield, 1937 to 1941, (unmanured) 2,000 lb. per acre. It gives 10 per cent higher yield than *Bhondu* which was so far the most prolific variety.

**(General yields during 1940 and 1941 are low on account of inadequate rains)**

## APPENDIX B

### Rice hybrids for fields infested with wild rice

***Description of morphological characters***
***(Rice Research Station, Raipur)***

| Characters | Cross No. 1 No. 17 × *Nagkesar* (Early) | Cross No. 2 *Nagkesar* × *Bhondu* (Medium) | Cross No. 5 *Nagkesar* × *Luchai* (Late) | Cross No. 19 *Budhiabako* × *Parewa* (Late) | Cross No. 116 *Bhondu* × *Parewa* (Medium) |
|---|---|---|---|---|---|
| Coleoptile | Dark purple | Dark purple | Dark purple | Purple | Purple. |
| Leaf sheath | Full purple (9) (P. Purple V. L. purple) | Full purple (9) (P. purple V. L. purple) | Full purple (9) (P. Purple V. L. purple) | Light purple (7) (P. L. Purple V.L. purple) | Light purple (7) (P. L. Purple V. L. purple) |
| Sheath axil | Purple (P. Purple V. White) | L. purple (P. L. Purple V. White) | L. Purple (P. L. Purple V. White) | Purple (P. Purple V. Purple) | Purple (P. Purple V. Purple) |
| Internode | Light green (1) | L. Yellow (2) | Light green (1) | Light green (1) | Light Yellow (2) |
| Leaf junctura | Green, mid-rib purple | Purple | Green, mid-rib purple | Dark purple | Dark purple |
| **Auricle** | **Purple** | **Purple** | **Purple** | **Dark purple** | **Dark purple** |
| **Ligule** | **Purple** | **Purple** | **Purple** | **White** | **White** |
| Pulvinus | Green, purp. spots | Green, purp. spots | Green, purp. spots | Dark purple | Dark purple |
| **Septum** | **Cream** | **Light brown** | **Cream, purp. spots** | **Purple** | **Brown** |
| **Leaf blade** | **Purple (3)** | **Purple (3) Broad** | **Purple (3)** | **Green** | **Green, Broad** |
| Glumes, early stage | Purple short | Purple short | Purple Short | White Short | White Short |
| **Glumes, ripe stage** | **L. purple** | **L. purple** | **L. purple** | **White** | **White** |
| Lemma and palea early stage | Light green, black spots (D) | Reddish orange (M) | L. purple, dark furrows (B) | Light green (F) | Reddish orange (M) |
| Lemma and palea ripe stage | Straw, black spots (d) | Reddish brown (m) | Brown furr. (b) | Straw (f) | Reddish brown (m) |
| | Ordinary hairy | Ordinary hairy | Ordinary hairy | Ordinary hairy | Ordinary hairy |
| Apiculus | Purple (G) | Purple (G) | Purple (G) | L. purple (F) | Purple spr. |
| **Stigma** | **Dark purple** | **Dark purple** | **Dark purple** | Dark purple | Dark purple |
| **Awns** | **Absent** | **Absent** | **Absent** | **Absent** | **Absent** |
| Habit | Spreading | Spreading | Erect | Spreading | Spreading |
| **Straw** | **Weak** | **Weak** | **Strong** | **Weak** | **Weak** |
| **Panicle** | Well ex. Com. Droop | Well ex. Com. Droop | Well ex. Com. Droop | Well ex. Com. Droop | Well ex. Com. Droop |
| **Rice, size** | **Medium** | **Coarse** | **Medium** | **Med.—fine** | **Coarse** |
| **Rice, colour** | **White** | **White** | **White** | **White** | **White** |
| **Rice, scent** | **Absent** | **Absent** | **Absent** | **Absent** | **Absent** |
| Rice, endosperm | Translucent with abd. wh. | Abdominal white | Translucent with abd. wh. | Translucent with abd. wh. | Abdominal white |

(B, D, 1, 3, etc. refer to coloured plates in " The description of crop-plant characters and their ranges of variation Rice ". *Indian J. agric. Sci.* VIII, V, Oct. 1938)

RICE HYBRIDS FOR FIELDS INFESTED WITH WILD RICE

*Description of quantitative characters*
*(Average of 3 years, 1939 to 1941)*

| Characters | Cross No. 1 No. 17 × *Nagkesar* (Early) | Cross No. 2 *Nagkesar* × *Bhondu* (Medium) | Cross No. 5 *Nagkesar* × *Luchai* (Late) | Cross No. 19 *Budhiabako* × *Parewa* (Late) | Cross No. 116 *Bhondu* × *Parewa* (Medium) |
|---|---|---|---|---|---|
| Height of plants | 106·2 ±2·101 | 135·4 ±1·519 | 117·5 ±1·330 | 115·4 ±1·906 | 111·3 ±1·451 |
| Number of tillers per plant | 1·80 ±0·143 | 1·77 ±0·135 | 1·91 ±0·173 | 2·17 ±0·195 | 1·73 ±0·149 |
| Flowering date | 19 Sept. | 14 Oct. | 21 Oct. | 15 Oct. | 13 Oct. |
| Days from sowing to flowering | 96 ±0·136 | 121 ±0·409 | 128 ±0·305 | 122 ±0·349 | 120 ±0·325 |
| Ripening date | 14 Oct. | 14 Nov. | 25 Nov. | 16 Nov. | 10 Nov. |
| Days from sowing to ripening | 121 ±0·316 | 152 ±0·408 | 163 ±0·577 | 154 ±0·224 | 148 ±0·707 |
| Length of panicle cm. | 22·72 ±0·680 | 24·71 ±0·539 | 21·55 ±0·483 | 22·18 ±0·471 | 21·3 ±0·63 |
| Number of grains per panicle | 120·0 ±9·296 | 139·9 ±6·658 | 179·3 ±9·695 | 115·7 ±6·67 | 103·7 ±5·72 |
| Sterility per cent | 6·12 ±1·546 | 11·55 ±1·920 | 4·38 ±0·979 | 13·73 ±1·745 | 14·39 ±1·890 |
| Grain length, mm. | 8·46 ±0·043 | 8·35 ±0·054 | 7·84 ±0·038 | 9·22 ±0·038 | 8·29 ±0·038 |
| Grain breadth, mm. | 3·07 ±0·017 | 3·46 ±0·023 | 2·69 ±0·017 | 2·47 ±0·009 | 3·37 ±0·013 |
| Grain, length/breadth | 2·75 ±0·019 | 2·42 ±0·015 | 2·91 ±0·021 | 3·74 ±0·020 | 2·46 ±0·016 |
| Rice, length, mm. | 6·27 ±0·033 | 5·98 ±0·043 | 5·64 ±0·028 | 6·50 ±0·065 | 5·89 ±0·030 |
| Rice, breadth, mm. | 2·55 ±0·012 | 2·90 ±0·015 | 2·20 ±0·011 | 2·03 ±0·008 | 2·86 ±0·013 |
| Rice, length/breadth | 2·45 ±0·012 | 2·07 ±0·018 | 2·58 ±0·024 | 3·20 ±0·047 | 2·06 ±0·016 |
| Weight of 1000 grains, gm. | 26·64 ±0·093 | 29·22 ±0·056 | 19·37 ±0·083 | 19·97 ±0·086 | 29·08 ±0·044 |
| Weight of 1000 kernels, gm. | 19·55 ±0·077 | 22·11 ±0·038 | 14·19 ±0·037 | 14·86 ±0·047 | 22·44 ±0·039 |
| Yield per plant, gm. | 5·32 ±0·231 | 5·59 ±0·322 | 5·25 ±0·327 | 4·35 ±0·204 | 5·17 ±0·310 |
| Milling quality. Whole rice per cent | 51·57 ±1·414 | 52·87 ±3·668 | 44·94 ±3·374 | 50·67 ±1·915 | 42·94 ±1·648 |
| Broken rice per cent | 19·27 ±1·049 | 19·67 ±2·288 | 21·93 ±4·267 | 15·93 ±2·662 | 26·13 ±1·176 |
| Husk and bran per cent | 29·16 ±0·619 | 27·46 ±1·443 | 33·13 ±0·671 | 33·40 ±1·245 | 30·93 ±0·532 |

# STUDIES IN INDIAN CEREAL SMUTS

## V. MODE OF TRANSMISSION OF THE KARNAL BUNT OF WHEAT

BY

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(Received for publication on 23 April 1942)

INTENSIVE work on the Karnal bunt of wheat due to *Neovossia indica* (Mitra) Mundkur is in progress at New Delhi since 1938. The primary object of this investigation has been to determine the mode of transmission of this disease. Without a precise knowledge of the manner in which it is disseminated from place to place and carried over from year to year, and of the methods by which it can be induced in experimental pots and plots, it is hardly possible to devise seed treatments or to develop resistant varieties. The bunt which was first discovered at Karnal is very common in parts of the Punjab and the North-West Frontier Province and reports of its occurrence in Saharanpur, a district of the United Provinces adjacent to the Punjab, have been recently received..

Since the inception of this work attempts have been made year after year to improve the technique so as to induce the appearance of the disease in infested pots. In the numerous pot experiments conducted during the past four years, only a single infected ear in 1941 and five infected ears in 1942 have been observed. The ear observed in 1941 was from an infested pot but of the five ears observed in 1942, two came from infested pots and three from controls. In all the other cases, the experiments have been a total failure.

### Methods of experimentation

*Soil*. Soil for these experiments was obtained from two sources, one being a field at Karnal where the disease had appeared in an epidemic form and the other a wheat field of the botanical section at New Delhi where bunt, as a rule, does not appear. It was sieved and manured before use and after setting apart a portion for the control pots, the rest was infested by bunt spores. This was done in the following manner. A thick suspension of spores that had been collected the previous season at Karnal was prepared. This suspension was black in colour due to the abundance of the spores. It was then thoroughly mixed with the soil and the soil was placed in pots. The pots were kept moist by sprinkling water over them and they were either placed indoors, or kept covered. Commencing 1939, some of the experimental pots were buried up to the brim in a field near the mycological section. Occasionally the pots were watered with suspensions of spores and the soil in them stirred.

*Seed.* Seeds from bunted ears (Imperial Pusa 165) were carefully examined to see if they were infected by the disease. Those seeds which showed the presence of the *sori* in their crease end were selected ; for the control pots, however, healthy seeds from non-bunted ears were chosen after examination with a hand lens for freedom from disease.

*Spores.* Bunted ears were dipped in clean water and vigorously rubbed so as to liberate the spores. When almost all the spores had been released, the husk was separated and the seed was collected, dried and stored for later use. The spores were allowed to settle down, the supernatant liquid was decanted and the spores were collected, air dried thoroughly, placed in vials and stored at a temperature of about 15°C. A large quantity of spores was collected each year in this manner.

For germinating the spores, they were first soaked in water for six days. On the seventh day, they were spread on a filter paper. This filter paper was then placed in a large petri dish and incubated at about 20°C. On the third day, the spores were found to put forth germ tubes and sporidia. Wheat seeds soaked in water for 24 hours, were then placed on the moist filter paper with the germinating spores and incubated at 20°C.

In 1941, the method of germinating the seed was slightly altered. An abundant quantity of spores was mixed with clean sand. The mixture was moistened, placed in a large dish in a room (where temperature ranged from 10°C. to 15°C.) at the end of September. The seed was germinated in this sand in the usual manner.

### *Experiments in 1938-39*

These experiments were carried out in 25 pots of 3 in. diameter with Delhi soil. Fifteen pots were filled with heavily bunt-infested soil and 10 pots served as controls. The soil was infested and the pots filled on 5 October 1938. Infested seed was sown in all the pots on the 28th of the month. Three seeds were sown in each pot.

Growth of the plants was satisfactory and the ears were harvested at the end of March. They were then carefully examined for the presence of bunt but none of the ears showed the disease.

### *Experiments in 1939-40*

Experiments on a more comprehensive scale were designed for 1939-40. In one set of experiments glazed pots of 12 in. diameter were buried up to the brim. Twenty-four of these pots were filled with Karnal soil that had been heavily re-infested. Sterilized Karnal soil was placed in six other pots. Another 12 pots were filled with Delhi soil of which six alone were infested with bunt spores. Soil was infested on 5 September 1939 and a second heavy suspension was added on the 15th of the month. The pots were kept moist and covered. The sowing plan is shown in Table I.

Bunt-free seed was sown in horizontal rows number I, III and V and infested seed was sown in the rest of the pots. Seed in the pots in the vertical row *a* was sown on 1 November 1939, vertical row *b* on 4 November and so on until 16 November. Ten germinated seeds were sown in each pot.

TABLE I

*Sowing plan of infected and control pots*

| Nature of the soil | Pot numbers | | | | | | |
|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | f | Remarks |
| I—Karnal soil, re-infested . . . . | 1 | 2 | 3 | 4 | 5 | 6 | Bunt-free seed |
| II—Karnal soil, re-infested . . . . | 7 | 8 | 9 | 10 | 11 | 12 | Bunted seed |
| III—Karnal soil, re-infested . . . | 13 | 14 | 15 | 16 | 17 | 18 | Bunt-free seed |
| IV—Karnal soil, re-infested . . . | 19 | 20 | 21 | 22 | 23 | 24 | Bunted seed |
| V—Karnal soil, sterilized . . . | 25 | 26 | 27 | 28 | 29 | 30 | Bunt-free seed |
| VI—Delhi soil, infested . . . . | 31 | 32 | 33 | 34 | 35 | 36 | Bunted seed |
| VII—Delhi soil, non-infested . . . | 37 | 38 | 39 | 40 | 41 | 42 | Bunted seed |

Growth was satisfactory and the ears were harvested on 30 March 1940. They were carefully examined for the presence of bunt but none of the grains was bunted.

In another experiment, the glazed pots used were of 6 in. diameter but they were not buried. They were filled with heavily infested Karnal soil as before and infested seed which, however, was not germinated was sown in all of them on 6 November at the rate of five seeds per pot. The depth at which the seed was sown was, however, different. The time taken by the radicle to emerge out of the soil depends to a certain extent on the depth of sowing. If this time is prolonged, then it is likely that the spores have a better chance to infect the seed. In one set of five pots, the seed was sown at a depth of half-an-inch, in a second at one, in a third at two, in a fourth at three, and in the fifth and the last at four inch depth. The growth of the plants was satisfactory and the ears were harvested on 29 March 1940. None of the grains showed bunt.

*Experiments in 1940-41*

The number of buried 12 in. pots was increased to 70 but the plan of soil infestation was as before. Instead of six as in previous year, the number of vertical rows was ten. Sowing in the first vertical row was done on the 29 October and continued in the rest of the rows on every fourth day until 25 November 1940.

Growth of the plants was satisfactory and the plants were ready for harvest on 13 April. The ears from each pot were separately collected and both the ears and the grain from them carefully examined for the presence of bunt. One diseased ear, of which four grains were completely bunted and seven partially bunted, was found in horizontal row III and in the pot sown on November 10. This pot had been filled with infested soil. None of the other ears was bunted.

In another experiment in 6 in. pots, 60 pots were filled with heavily infested Delhi soil and infested seed which had not been germinated in petri dishes was sown, at the rate of five seeds per plot, on 22 November. McAlpine [1910] states that if oat plants are cut back before heading time and induced

to tiller, these tillers usually show heavier infestation by loose smut. Hoping that such cutting back might induce bunt, plants in one lot of eight pots were cut back on 10th in a second lot on 20th and a third lot on 30th December, respectively. The rest served as controls. The ears were harvested on 8 April 1941. They were carefully examined but none of the ears was bunted.

*Experiments in 1941-42*

The tests in the 70 buried pots were repeated in 1941-42. Two infested ears were found in horizontal row IV, sown on November 16 and three in two pots in horizontal row V, sown on November 16 and 19, respectively. In this latter row, the pots were filled with sterilized Karnal soil and healthy seed had been sown. In all the rest of the pots, there was no bunt.

## Discussion of results

The results presented above furnish overwhelming evidence which leads to the conclusion that the Karnal bunt is neither seed-borne or soil-borne. In the course of these experiments, naturally-infested seed was sown in bunt-infested soil and disease-free soil; and bunt-free seed was sown in soil heavily-infested with bunt spores. In addition, naturally-infested seed which was germinated in the presence of germinating spores was also sown in heavily-infested soil. In almost all cases, however, negative results have been repeatedly obtained. In 1941, one infested ear was found in a pot which contained infested soil and two such ears were found in 1942. As against these, three ears were found in 1942 in pots containing soil free from bunt, in which disease-free seed had been sown. It appears to be more than likely that this is natural infection but how such infection takes place in nature, it has not been possible to ascertain. It does not seem to be via the seed or the soil. Along with the head smut of maize [*Sorosporium Reilianum* (Kuehn) McAlpine], the long smut of *jowar* [*Tolyposporium Ehrenbergii* (Kuehn) Patouill.] and certain other smuts, the mode of transmission of this smut will also have to remain a mystery for the time being.

In the loose smut of wheat [*Ustilago Tritici* (Persoon) Rostrup] infection is floral and it takes place at the time of anthesis. But at the time the stigmas are in a receptive state, the spores of the smut are already present in great abundance, for smutted ears appear a little earlier than the flowers. In the case of Karnal bunt, the disease does not become manifest until the ears are mature and ready for harvest at which time there are no wheat flowers at all. There is, therefore, little likelihood of infection being floral.

Is it safe then to recommend seed treatments to control the disease? When heavily-infested wheat seed has consistently failed to produce the disease in the resulting crop, it appears as though such treatments will not be of much avail.

## Summary

The Karnal bunt of wheat (*Neovossia indica*) is prevalent in the Punjab and the North-West Frontier Province and may occur in the north-western districts of the United Provinces.

Attempts have been made to bring about this disease in pot experiments since 1938. Disease-free seed was sown in heavily-infested soil and bunted seed sown in disease-free soil and also heavily-infested soil. Bunted seed was also sown in infested soil at different depths. Plants raised from bunted seed in infested soil were cut back to induce tillering with the hope that bunt would appear in the tillers. In almost all cases completely negative results have been obtained.

Throughout the course of these experiments, three bunted ears appeared in infested pots but they also appeared in control pots that contained disease-free soil and were sown with disease-free seed. These few cases appear to be natural infections but it has not yet been possible to ascertain how such infection takes place in nature.

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# PROPERTIES OF SYNTHETIC MIXTURES OF COLLOIDAL SOLUTIONS OF SILICIC ACID AND ALUMINIUM HYDROXIDE, I*

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(With two text-figures)

PREVIOUS investigations from this laboratory [Mukherjee, *et al.* 1937; Mitra, 1936, 1940; Mitra *et al.* 1940; Chatterjee, 1939] show that colloidal solutions of some hydrogen clays resemble silicic acid so far as they show in common an inflexion point in the acid region when titrated with bases. The total acidity depends on cation effects.** The present investigations on the properties of mixed gels have been undertaken on the lines of the work on hydrogen clays, pure gels and pure minerals which has been done in this laboratory.

Bradfield [1923] studied the physico-chemical properties of a synthetic mixture of purified aluminium hydroxide, ferric hydroxide and silicic acid having the same composition as the colloidal material isolated from a heavy clay subsoil. He observed that the natural clay considerably differs from the artificial mixtures as regards (*i*) velocity of migration in an electric field; (*ii*) buffer action towards alkalis; (*iii*) flocculation; and (*iv*) the amounts of Al, Fe and Si brought into solution by acids and alkalis. The synthetic sol was positively charged while the natural colloid was negative. The former showed a stronger buffering towards alkalis than the latter and was most readily flocculated by polyvalent anions in the alkaline medium; the natural colloid was, on the other hand, most sensitive to multivalent cations in an acid medium. The artificial mixture was more soluble in dilute acids and alkalis than the natural clay. From these observations he concluded that there were differences between the two regarding their chemical constitution. Mattson [1928, 1930] prepared synthetic systems by mixing increasing amounts of sodium silicate solution with aluminium chloride solution and obtained successively an electro-positive, an iso-electric precipitate and finally with an excess of silicate an electro-negative sol. A series of iso-electric precipitates

* The results have been published in the Annual Report for 1939-40 on the working of a scheme of Research into the Properties of Colloid Soil Constituents financed by the Imperial Council of Agricultural Research. A Note on this subject has been published in the Proceedings of the Indian Science Congress Association, 1941.

** The total acidity has been found to depend on (*i*) $p$H and (*ii*) the nature of the base with which the sol is titrated.

were also prepared in which the proportion of silica decreases with an increase in the iso-electric *p*H approaching zero at *p*H 7·0. It was found that the molecular ratio between the constituents reaches a maximum but remains always less than three. The iso-electric *p*H is about five for precipitates of this composition. The amount of silica in the precipitate could be increased by adding suitable cations whereas in the presence of multivalent anions the proportion of alumina is increased. The precipitates are electro-positive in an acid medium and electro-negative in an alkaline medium. Their base exchange capacities increased with the ratio of silica to alumina and were of the magnitude observed with natural soil colloids. Mattson considers that silicate ions enter into the sesquioxide complex and lowers the iso-electric *p*H as a result of the displacement of diffusible anions including hydroxyl ions by the silicate ions.

Bhattacharya and Ganguly [1936] and Bhattacharya [1937] have studied gels of silica, alumina and ferric oxides and their mixtures. They observed that the mixed gels adsorbed cations in excess of that calculated for their components. The pure gels take up most water when saturated with Na, whereas the mixed gels have the greatest capacity when saturated with Mg. The retention of water was at a maximum at a silica-sesquioxide ratio of 1·4. Mixed gels containing $SiO_2$ and $Al_2O_3$ or $Fe_2O_3$ saturated with various cations have cataphoretic velocities in the order Na $>$ K $>$ Mg $>$ Ca $>$ H and the reverse order was observed for mixed gels containing $Al_2O_3$ and $Fe_2O_3$.

Anderson and Byers [1936] titrated a mixed gel of aluminium hydroxide and silicic acid with caustic soda. Their titration curve shows a weak acid character and a strong buffer action in the region of *p*H 6·5.

TABLE I

*Changes in the* p*H and specific conductivity of the mixed sols with time*

| Systems* | Colloid content gm. per litre | *p*H | | | Specific conductivity $\times 10^5$ mho | | |
|---|---|---|---|---|---|---|---|
| | | After 24 hrs. | After 1 week | After 3 weeks | After 24 hrs. | After 1 week | After 3 weeks |
| 1 Silicic acid sol . | 5·87 | 4·10 | 4·09 | 4·10 | 1·63 | 1·60 | 1·62 |
| 2 Mixed sol 2 : 1 . | 5·88 | 4·09 | 4·05 | .. | 2·71 | 3·45 | 4·50 |
| 3 Mixed sol 1 : 1 . | 5·88 | 4·20 | 4·53 | 4·64 | 2·38 | 2·62 | 3·52 |
| 4 Mixed sol 1 : 2 . | 5·88 | 4·51 | 4·82 | 4·76 | 2·20 | 2·32 | 3·20 |
| 5 Aluminium hydroxide sol | 5·88 | 6·20 | 6·25 | 6·24 | 2·80 | 2·86 | 2·82 |

* Molar ratios of $SiO_2/Al_2O_3$

Sols of silicic acid and hydrous alumina were prepared and purified in the same manner as previously described [Mukherjee *et al.* 1934, 1936; Chatterjee, 1939]. Three synthetic mixtures were prepared by adding increasing amounts of colloidal hydroxide to a definite volume of silicic acid sol. Mutual coagulation took place as shown by the presence of flocks but no appreciable sedimentation was observed till about three weeks had passed. In view of the heterogeneous character of the resulting mixture it was thought desirable to study the variations in the *p*H and specific conductivity of the mixed sols with time. The results are shown in Table I.

The data cited above show that the *p*H and specific conductivity of the synthetic mixtures change with time. The variations show the presence of a slow interaction between colloidal silicic acid and aluminium hydroxide-

## Interaction with alkalis

The free and total acids of the synthetic mixtures as also those of colloidal silicic acid and aluminium hydroxide are given in Table II. The total acids have been calculated both at inflexion points and at *p*H 7·0 in the titration curves.

### Table II

*Free and total acids of the mixed sols*

| System | *p*H | Free acidity $\times 10^5 N$ | Total acidity $\times 10^5 N$: At inflexion point | Total acidity $\times 10^5 N$: At *p*H 7·0 | *p*H at inflexion point |
|---|---|---|---|---|---|
| 1 Silicic acid sol . | 4·09 | 8·1 | 16·0 | 37·0 | 4·9 |
| 2 Mixed sol 2 : 1 . | 4·05 | 8·9 | 78·0 (17·0)* | 78·0 | 7·0 (4·5)* |
| 3 Mixed sol 1 : 1 . | 4·50 | 3·0 | 77·0 | 72·0 | 7·2 |
| 4 Mixed sol 1 : 2 . | 4·82 | 1·5 | 78·0 | 67·0 | 7·4 |
| 5 Aluminium hydroxide sol | 6·20 | 0·09 | .. | 16·0 | .. |

* At first inflexion point (*p*H 4·5)

The potentiometric titration curves (Fig. 1) of the mixtures with NaOH do not resemble those of either the aluminium hydroxide or the silicic acid sols and show definite inflexion points between *p*H 6·5 and 7·5 as observed in the titration curves of some hydrogen clay and bentonite sols [Mukherjee, *et al.* 1937; Mitra, *et al.* 1940]. The mixture having $SiO_2 : Al_2O_3$ ratio of 2 : 1 shows two inflexion points, one in the acid region (*p*H 4·5) as observed with

silicic acid sols [Chatterjee, 1939]. As the percentage of silica in the mixture increases the inflexion point found between $p$H 6·5 and 7·5 gains in sharpness.

The amounts of acid neutralized at $p$H 7·0 also increase with the silica contents of the mixtures. At the inflexion point, however, they do not differ widely from one another but the $p$H at inflexion point slightly decreases with increasing silica content.

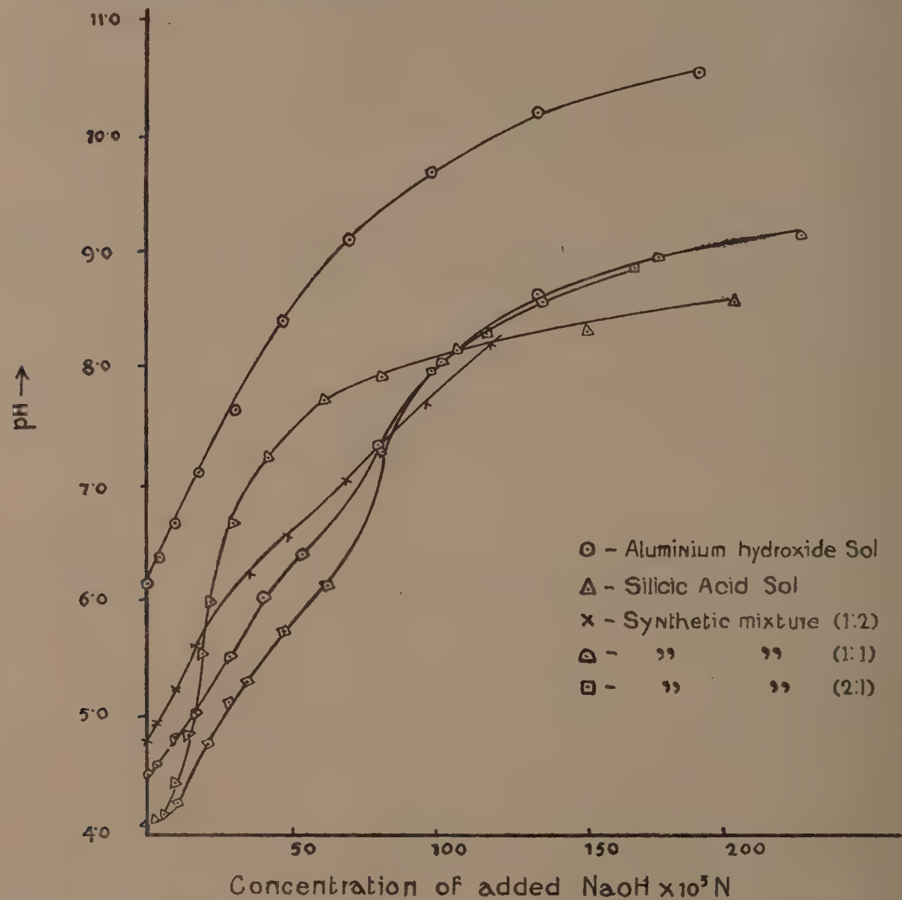


Fig. 1. Potentiometric titration curves of the synthetic mixtures as also those of colloidal silicic acid and aluminium hydroxide with sodium hydroxide

### Buffer capacity

The buffer capacities ($\triangle B/\triangle p$H) at different points in the titration curves of silicic acid sol, synthetic mixtures and colloidal aluminium hydroxide are plotted against the concentration of added alkali in Fig. 2. The buffer capacity curves of the mixtures do not resemble those of either silicic acid or aluminium hydroxide sols. The buffer capacity calculated by adding those

of the individual components at a given concentration of the alkali, is considerably higher than that obtained with synthetic mixtures.

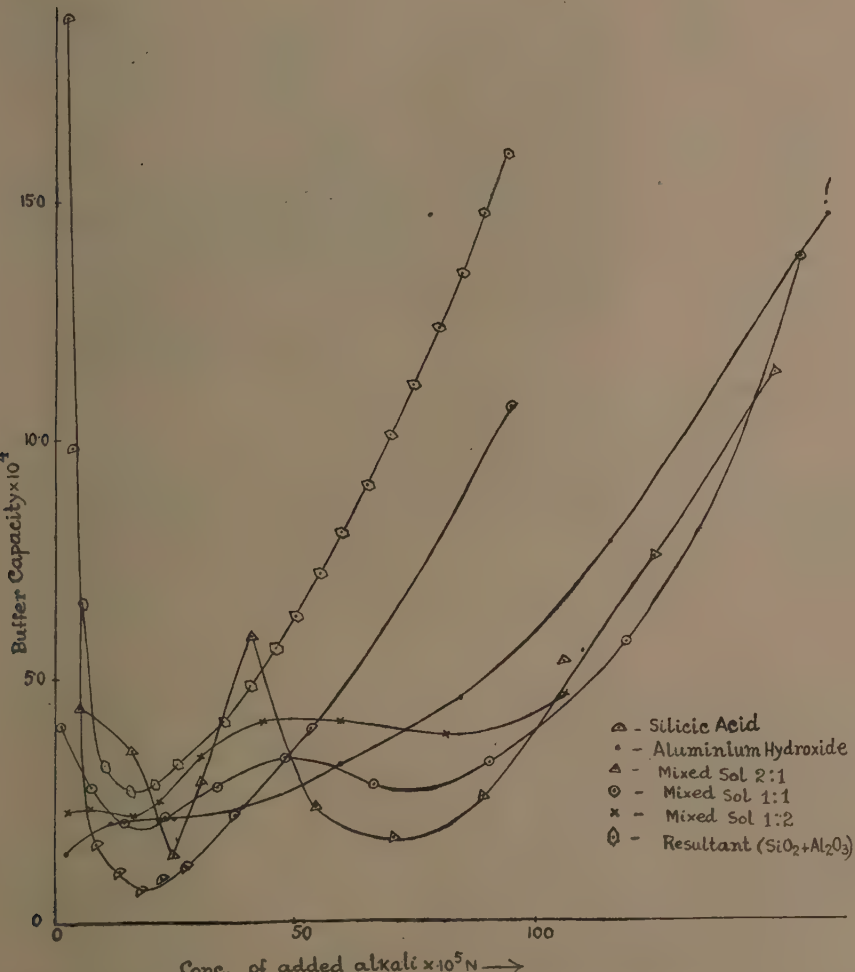


FIG. 2. Buffer capacity curves of silicic acid sol, synthetic mixtures and colloidal aluminium hydroxide

### CHARGE MEASUREMENTS

The synthetic mixtures used in this work were all electro-positive (Table III). A micro-cataphoretic cell of the Abramson type was used for this purpose.

TABLE III

*Sign of the charge of the synthetic mixtures and their appearance under the microscope*

| System | Sign of charge | Appearance under microscope |
|---|---|---|
| 1 Silicic acid sol . . . | — | |
| 2 Mixed sol 2 : 1 . . . | + | Number of small particles very few; larger particles move more slowly |
| 3 Mixed sol 1 : 1 . . . | + | Number of small particles few |
| 4 Mixed sol 1 : 2 . . . | + | Small particles are found in greater numbers to collide with the bigger ones and vanish out of sight |
| 5 Aluminium hydroxide sol . | + | |

It is interesting to note that the mixture having $SiO_2 : Al_2O_3$ ratio of 2 : 1 is electro-positive. Similar results have been obtained by Bradfield [1923] who found that a mixture having $SiO_2 : Al_2O_3$ ratio of 1·85 : 1 was electro-positive.

## Summary

The *p*H and specific conductivity of the mixtures change with time showing the presence of a slow interaction between colloidal silicic acid and aluminium hydroxide.

The potentiometric titration curves of the mixtures with NaOH do not resemble those of either the silicic acid or aluminium hydroxide sols. They show inflexion points between *p*H 6·5 and 7·5.

The total acid of the mixtures calculated at *p*H 7·0 increases with their silica content but at the inflexion points they give almost identical values. The *p*H at inflexion, however, increases with the alumina content.

The buffer capacity curves of the mixtures do not resemble those of colloidal silicic acid or aluminium hydroxide sols.

The synthetic mixtures used in this work were all found to carry a positive charge.

## Acknowledgements

The authors take this opportunity to offer their sincere thanks to Prof. J. N. Mukherjee for suggestions and to the Imperial Council of Agricultural Research, India, for financial help in carrying out this work.

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# SOILS OF THE DECCAN CANALS

## III. STUDIES ON THE EFFECT OF VARIOUS ROTATIONAL CROPS AND GREEN MANURES ON THE SOIL AND ON THE SUCCEEDING CANE CROP, WITH SPECIAL REFERENCE TO SOIL STRUCTURE

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(Received for publication on 17 April 1942)

(With Plate II and one text-figure)

### Introduction

THE value of suitable crop rotations in any system of crop growing for the purpose of maintenance of soil fertility is well known, it being a long-standing experience with farmers in all countries that crops grow better in rotation than in continuous succession. This aspect of agricultural practice assumes an additional importance under the trying conditions of irrigation, farming, and particularly under cane growing, in the Bombay-Deccan where the cane crop remains for a long time on the land. On an examination of the crop rotations ordinarily practised in the tract it was apparent that the success of maintaining soil productivity was largely linked up with the period of rest from cane-growing that each of the rotational systems would provide, those with proportionately longer periods under cane being considered to be exhausting. However, it seems to be quite probable that different rotational crops may have certain pronounced effects on the soil condition. Actually, some of these crops are believed to exert a depressing effect on the yield of the succeeding cane crop. Therefore, in the working out of systems of crop rotations suitable for a general agricultural practice for the canal areas which would ensure the maintenance of soil fertility and of cane yields at a high level it was considered imperative that detailed soil investigations on the effect of crop rotations should be first undertaken.

*Historical*

The scientific knowledge that can be drawn upon to supply points for guidance for these studies is, unfortunately, rather meagre, except perhaps on the question of green manures as affecting soil fertility. The memorable

*This scheme is partly subsidized by the Imperial Council of Agricultural Research

experiment carried out by Boussingault between 1834-41 [Russell, 1937] dealt with various rotations in order to see which was the most efficaceous. From the analyses of the crops and manures applied in each rotation he arrived at the conclusion that, other things being equal, the best rotation is one which yields the greatest amount of organic matter over and above what is present in the manure. But no account was taken of the balance remaining in the soil. The classical investigation of Daubeny in 1845 [Russell, 1937] was conducted mainly from the point of view of testing the hypothesis of the toxic effect of crops on those following them but he was unable to prove the existence of any toxins. He showed that in continuous cropping the decrease in yield was due to the more rapid removal of mineral nutrients required by that particular crop. Since then, although long-continued field experiments with different crops have established the superiority of crops in rotations to continuous cropping [Weir, 1926], no explanation of the exact causes of such differences is yet forthcoming from the point of view of soil studies. A direct approach to soil problems involved in crop rotations is found in the work of Odland and Smith [1933] where they have reviewed the results of the past work in this direction. They have grouped the various hypotheses put forth by different workers for explaining the effect of certain crops on succeeding crops under the following four heads :

(*i*) Crops that remove excessive quantities of mineral elements tend to impoverish the soil for those elements.

(*ii*) Crops that remove the greatest excess of elements that are chemically basic over those that are acidic create the greatest degree of soil acidity and correlated toxicity.

(*iii*) Crops that provide residues relatively high in carbohydrates and low in nitrogen are decomposed by micro-organisms at the expense of soil nitrogen, decreasing the supplies available to crops.

(*iv*) Certain crops may excrete organic toxins from the roots or the decomposition of plant residues may leave organic toxins in the soil temporarily or permanently.

From the results of 25 years' experimentation at the Rhode Island Agricultural Experiment Station these authors were able to find support for the first two hypotheses but no definite conclusions could be drawn regarding the rest, although in the case of corn it was found that the relative nitrogen removal by the preceding crops was correlated with yield. It may be noted in this connection that the explanation offered under (*ii*) above cannot account for the differential effects of rotational crops in the soils under the present study as they are highly calcareous, and changes, if any, introduced by cropping are usually counteracted by the lime reserves in these soils.

The beneficial effects of green manuring by burying in leguminous crops in enhancing the nitrogen contents of soils and the yields of succeeding crops are already too well known and need not be discussed here. It has also been claimed by certain Russian workers [Russell, 1938] that fallowing (where grasses are allowed to grow) and growing of certain leguminous plants help in the building up of a desirable soil structure. But no comprehensive data, especially for Indian soils, on the effects of commonly grown rotational and green manure crops on tilth and other soil properties, are available. It is

proposed to deal with this aspect of the problem in a series of papers in order to arrive at a scientific basis of crop rotations for sugarcane for different soil types in the canal zones of the Bombay-Deccan.

*Outline of work*

For the purpose of our study three of the more common rotational crops ordinarily grown in the tract, and which were likely to fit into the general economics of agricultural practice, were chosen. These were groundnut, cotton and fodder *jowar* (*Andropogon sorghum*). At the same time, as green manuring has come to be accepted as a standard practice included in sugarcane rotations two of these were included for study. One of them was sunn-hemp (*Crotalaria juncea*) and the other was a leguminous weed locally called *patada shevra* (*Desmodium diffusum*) (Plate II), which was isolated at the station and, in preliminary trials, had shown promise of being a good substitute for sunn under certain conditions. The sixth and last treatment taken up for these studies was fallow, where weeds were encouraged to grow by a few waterings given during dry spells and the green matter ploughed in before the weeds produced seed, so as to avoid trouble by excessive weediness later on. The fallow treatment was included in order to provide a control as well as to meet the needs of certain large-scale cane growers, particularly sugar factories, who do not find it convenient to grow intermediate rotational crops but leave the land fallow allowing natural vegetation to come up. For all practical purposes fallow, therefore, can be considered as a sort of green-manuring treatment and has been treated as such in the following discussions. Sugarcane was grown after these treatments with uniform cultural operations, irrigation and manuring.

In the present investigations, we set ourselves to determine mainly (*i*) the general effect of each of the treatments on the soil and (*ii*) the behaviour and growth of sugarcane immediately following these treatments. Special prominence has, however, been given to the study of soil tilth, as a deterioration of this soil condition is believed to be reflected in the general loss of heart of the soil occurring in cane areas due to exhausting cropping.

## Experimental

*Field experiment*

The following six rotational treatments were laid out according to the randomized block system with four replicates for each treatment :—(1) cotton (2) groundnut (3) fodder *jowar* (4) sunn (5) fallow and (6) *patada shevra*. The gross plot size was 40·8 ft. ×28 ft. (1·04 *guntha* or 2·6 cents). Sufficient room between adjacent blocks and plots was provided to admit of separate cultural operations for the treatments but when cane was grown these intervening spaces were also planted so as to avoid exposure of isolated plots of cane to wind. The central plot, after leaving out a border, measured 36·8 ft. ×20 ft. (0·68 *guntha* or 1·7 cents). The experiment was carried out on the Padegaon farm on a typical black cotton soil designated as 'B' type according to the classification adopted at the station [Basu and Sirur, 1938].

*PATADA SHEVRA* (*Desmodium diffusum*)

(A new green manuring crop under trial at the Padegaon Station - fully mature crop with the roots exposed)

The *kharif* crops were grown in 1936 according to the usual methods of cultivation followed in the tract. The time of sowing for the various crops occurred between the first week of May (for cotton) to the second or third week of June for *jowar* and groundnut. The number of irrigations varied from three to four for different crops according to their needs. Fallow was irrigated at the time of sowing sunn and then again two or three times during dry weather to encourage weed growth. Regarding the disposal of crops, the green-manuring crops (in which fallow is included) were ploughed under at the flowering stage.

The preparatory tillage for cane excluding the ploughing for green-manure crops which was given at the time of burying the crops, consisted mainly of one ploughing by gallows plough. In the case of green-manuring crops this is usually given in middle to late November when the land comes into condition after the stoppage of the rains; but in the case of rotational crops whose growth period extended beyond the rainy season, e.g. in cotton and groundnut, the ploughing was given soon after harvest of the crops. The period of ploughing for the different crops thus varied between mid-November to early December. This may be taken as the main-tilth-producing operation as the soil is left, subsequent to ploughing, to the weathering action of the atmosphere for about a month or more. The land was then worked with a disc harrow, and finally laid in ridges and furrows for cane planting in January.

Subsequently cane was grown in the season of 1937-38 with identical manurial and cultural operations, the details of which are given later.

*Methods employed*

The laboratory and field methods followed for determining the various soil properties are described below:

*Soil tilth.* The method developed by Keen [1931] at Rothamsted for measuring the effect of cultivation implements on the soil was followed for determining soil tilth. Fresh samples of soil from the field were made to pass through a bank of sieves of decreasing mesh size (having, in order, square meshes with length of sides $1\frac{1}{2}$ in., $\frac{5}{8}$ in., $\frac{1}{4}$ in., and finally round holes 3 mm. in diameter) and the fractions so separated were weighed. A single value index for soil tilth on the basis of relative surface area was calculated as recommended by Keen. The method was previously standardized by working on a large number of soil samples and the number of movements to be given to each sieve for effective separation of the fractions was worked out so as to reduce the personal error to a minimum. The determination was also done on a sufficiently large number of replicates so as to reduce the standard error within a reasonable limit.

*Dispersion coefficient.* This was taken as the ratio of clay obtained by the dispersion of the fresh soil by water alone to the total clay obtained by the International method of mechanical analysis.

*Oxygen-giving power.* Determined by the change in colour produced in an aqueous solution of 'aloin' by shaking up fresh soil with the solution and comparing the colour with standard 'aloin' solution as recommended by Waksman [1931].

For the sake of economizing space the methods already described in previous publications of the series have not been given here.

## Presentation of data and discussion

The rotational crops were grown in the *kharif* season of 1936. The yields of all the crops were satisfactory and are given in Table I.

With the first ploughing soon after the harvest of the crops, tilth was determined by the field sieving method. The figures of this determination will be, however, considered later when discussing the seasonal changes in tilth.

TABLE I

*Dates of sowing and harvesting and average yields in different* kharif *rotational crops*

| Treatment | Date of sowing | Date of harvest | Approximate period of growth | Yield per acre (lb.); averages of four replicate plots |
|---|---|---|---|---|
| Groundnut . . | 16 June 1936 | 14 December 1936 | 6 months . | 3,520 (dry pods) |
| Cotton . . . | 3 May 1936 . | 2 December 1936 (final packing) | 7 ,, . | 1,904 (seed cotton) |
| *Jowar* . . . | 2 July 1936 . | 16 October 1936 | 3½ ,, . | 22,125 (green fodder) |
| Fallow . . . | 21 May 1936 (first irrigation) | 10 September 1936 | 3½ ,, . | 10,673 (green weeds) |
| Sunn . . . | 21 May 1936 | 18 August 1936 | 3 ,, | 22,409 (green matter) |
| *Patada shevra* . . | 21 May 1936 | 14 September 1936 | 3½ ,, . | 14,976 (green matter) |

*Soil studies before cane planting*

The main soil studies, which were done in great detail, were undertaken in January 1937, and may be classed in two categories : (*a*) soil tilth and properties expected to be closely associated with this condition and (*b*) fertility factors. Most of these were done in as large a number of replications as possible so as to allow of their being statistically worked out. The determinations and number of replicate observations for each are given in Table II. For the present discussion, however, only the average figures for the various properties and their bearing on the general soil condition and on the subsequent cane crop will be dealt with. The statistical part of the work will be published separately along with other replicated data of soil analyses.

TABLE II

*Number of replicate observations taken for the different soil properties*

| | Number of observations per plot | Total number of observations for each treatment |
|---|---|---|
| (*a*) Soil tilth, etc. | | |
| 1. Single value index for tilth by field-sieving | 20 | 80 |
| 2. Moisture | 10 | 40 |
| 3. Nitrate | 10 | 40 |
| 4. Oxygen-giving power | 5 | 20 |
| 5. Dispersion coefficient | 1 | 4 |
| 6. Bacterial number | .. | 1 |
| (*b*) Fertility factors | | |
| 1. Nitrogen | 1 | 4 |
| 2. Humus | 1 | 4 |
| 3. Carbon | 1 | 4 |

The average single-value figures for soil tilth, the dispersion coefficient and moisture are given in Table III.

It may be seen that the soil tilth is best after *patada shevra* followed more or less closely among themselves by the treatments *jowar*, cotton and groundnut, tilth after fallow and sunn being comparatively inferior. This latter result is rather unusual, the general expectation being that green manuring should have improved the condition of soil tilth. The only explanation that can be offered for this phenomenon is that the burying in of sunn (and weeds in fallow in the present case) has to be finished during breaks in the rains which keep the land more or less continuously wet during late August and in September. Consequently, it is likely that the soil structure might have been temporarily destroyed to a certain extent due to the slightly wet condition of the soil at the time of ploughing. But this was unavoidable. It is interesting to note that Russell and Keen [1938] have observed a similar difficulty of carrying out tillage operations at the proper time in their work on the effect of cultivation on crop yield. Dispersion coefficient, on the principle of lower dispersion indicating better tilth, shows somewhat the same trend, although not exactly in the same order, which in this case is cotton, *patada shevra*$>$ *jowar*, groundnut$>$sunn$>$fallow. It thus shows a fairly good agreement with tilth by sieves. Moisture shows a certain amount of variation among

the treatments and is, except in groundnut, higher where tilth is inferior, e.g. in sunn and fallow. There are two aspects of the moisture content of the soil to be considered. One is, how various factors under the different crops have contributed towards the present moisture status of the soil. Second is, how this moisture condition has affected the separation of the natural aggregates by sieving which has been discussed below in connection with the relationship with tilth and other properties. With regard to the first aspect, making due allowances for other factors which may have been responsible for modification of soil moisture, there is perhaps yet some scope for the interpretation that the higher moisture content in treatments with inferior tilth (excepting groundnut ) has been due to the holding up of the moisture in the upper layers on account of imperfect drainage caused by bad tilth.

TABLE III

*Average single-value figures for tilth, dispersion coefficient and moisture in soil after different rotational treatments*

| Treatment | Single-value index for soil tilth | Dispersion coefficient | Moisture per cent |
|---|---|---|---|
| Groundnut | 238±5·2 | 48·40 | 27·3±0·609 |
| Cotton | 243±5·0 | 31·05 | 24·8±0·667 |
| Fodder *jowar* | 253±7·1 | 46·93 | 21·2±0·785 |
| Fallow | 195±5·3 | 62·64 | 26·4±0·649 |
| Sunn | 184±4·9 | 52·20 | 28·1±0·552 |
| *Patada shevra* | 276±7·9 | 33·24 | 25·2±0·991 |

Average bactertial numbeı, nitrate and oxygen-giving power are shown in Table IV.

Generally speaking, the green-manuring treatments in which fallow has been included are superior both in bacterial number and the nitrate content to the other treatments, the effect, if any, of the condition of soil tilth being completely masked by the effect of addition of green matter. Among the green manures, the green matter incorporated (Table I) has caused a proportionate increase in nitrate but not in bacterial number. The oxygen-giving power was expected to be more with better tilth and the figures, which are direct colorimetric readings with a standard 'aloin' solution, should be comparatively lower in the case of treatments with better tilth. There is, however, no consistency that can be seen in the data.

TABLE IV

*Average bacterial number, nitrate and oxygen-giving power in soil after different rotational treatments*

| Treatment | Bacterial number | Nitrate ($NO_3$-N) | Oxygen-giving power* |
|---|---|---|---|
| | per gm. of dry soil | mg./100 gm. dry soil | |
| Groundnut | 56,000 | $0 \cdot 03 \pm 0 \cdot 0090$ | $2 \cdot 68 \pm 0 \cdot 1712$ |
| Cotton | 23,750 | $0 \cdot 02 \pm 0 \cdot 0054$ | $3 \cdot 56 \pm 0 \cdot 2159$ |
| Fodder *jowar* | 32,000 | $0 \cdot 02 \pm 0 \cdot 0046$ | $3 \cdot 10 \pm 0 \cdot 1688$ |
| Fallow | 116,000 | $0 \cdot 06 \pm 0 \cdot 0105$ | $3 \cdot 12 \pm 0 \cdot 2655$ |
| Sunn | 67,500 | $0 \cdot 29 \pm 0 \cdot 0480$ | $3 \cdot 34 \pm 0 \cdot 2135$ |
| *Patada shevra* | 158,750 | $0 \cdot 14 \pm 0 \cdot 0042$ | $3 \cdot 09 \pm 0 \cdot 2032$ |

*Direct colorimetric readings with a fixed height of standard 'aloin' solution

The general relations between the tilth and other properties are well brought out in Fig. 1.

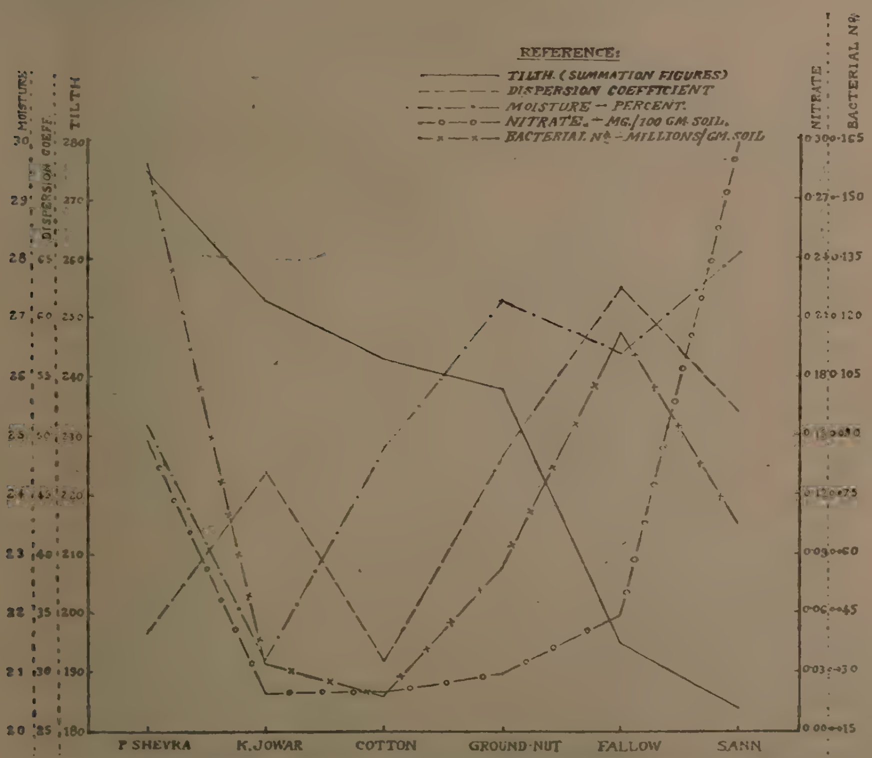


FIG. 1. Relationship between tilth and other associated soil properties

Here the tilth figures, arranged in descending order, have been joined by an entire line and the other corresponding properties (excepting oxygen-giving power) have been plotted and joined by various other distinguishing lines. It can be seen that the curve for dispersion coefficient runs more or less in the opposite direction to that of the tilth curve, thus showing the inverse relation between the two types of determination of the same soil property. The moisture curve shows for the greater part of its course a fairly good parallelism with the dispersion-coefficient curve, thus indicating the relation between the two. The nitrate and bacterial number curves are independent and form nearly parallel trough-like figures.

In considering the effects of the crops on the fertility factors, it was thought better to see to what extent the different treatments have modified the original level of these constituents rather than compare the figures only at the end of the experiment. In Table V nitrogen and humus contents of the soil, before and after the different treatments and their ratios with the original as 100, are given.

TABLE V

*Average nitrogen and humus contents of soil before and after different rotational treatments*

| Treatment | Nitrogen (mg. per 100 gm. soil) | | | Humus (per cent) | | |
|---|---|---|---|---|---|---|
| | Original | Final | Ratio with original as 100 | Original | Final | Ratio with original as 100 |
| Groundnut | 49·9 | 51·1 | 102·4 | 0·68 | 0·65 | 95·6 |
| Cotton | 50·7 | 53·8 | 106·1 | 0·72 | 0·69 | 95·8 |
| Fodder *jowar* | 53·0 | 49·8 | 94·1 | 0·70 | 0·71 | 101·5 |
| Fallow | 52·3 | 54·2 | 104·1 | 0·69 | 0·66 | 95·6 |
| Sunn | 53·4 | 57·7 | 110·0 | 0·72 | 0·71 | 98·6 |
| *Patada shevra* | 49·6 | 54·7 | 113·9 | 0·66 | 0·69 | 104·6 |

A general scrutiny of the figures shows that the nitrogen status of the soil has been appreciably raised by sunn and *patada shevra* to the extent of 10 and 13·9 per cent respectively. Fallow has been very successful as the increase of 4·1 per cent cannot be considered as appreciable. Among the other treatments, cotton tends to enhance the nitrogen level while *jowar* has slightly depressed it. Groundnut has caused very little change. Comparing the actual nitrogen content of the soil after the treatments (i.e. the nitrogen leve

which would be further directly useful for the succeeding cane crop) it may be observed that it is the highest in sunn followed with small variations among themselves by *patada shevra*, fallow and cotton. Groundnut and *jowar* are comparatively poor. An important point which would have to be considered in this connection is the ease with which this nitrogen in various treatments would mineralize and supply available nitrogen and there is an indication from the higher nitrate figure in the green manure treatments that the nitrogen in these plots is more readily available. With regard to humus there seems to be a general tendency for lowering of this constituent, even in the green-manuring treatments. It is not clear whether in these latter treatments, where considerable amounts of organic matter have been added, this is due to rapid oxidation and consequent loss of organic matter under tropical conditions.

As is well known, C/N ratio is an important factor in controlling the biological activities of the soil, and in fertility investigations on cane soils conducted at this station, it was found to be one of the main clues to the state of temporary soil exhaustion. It was, therefore, felt desirable to examine the C/N ratios of the soil as affected by the rotational treatments and how they were likely to affect the succeeding cane crop. In Table VI average figures for carbon and C/N ratios before and after the rotational treatments are given.

TABLE VI

*Average carbon contents of soil and C/N ratios before and after different rotational treatments*

| Treatment | Carbon | | | C/N ratio | | |
|---|---|---|---|---|---|---|
| | Original | Final | Final as percentage of original | Original | Final | Final as percentage of original |
| | per cent | per cent | | | | |
| Groundnut . . | 1·23 | 1·17 | 95·1 | 24·7 | 23·0 | 93·1 |
| Cotton . . . | 1·21 | 1·24 | 102·5 | 23·9 | 23·0 | 96·2 |
| Fodder *jowar* . . | 1·23 | 1·19 | 96·7 | 23·3 | 23·9 | 102·5 |
| Fallow . . . | 1·17 | 1·11 | 94·8 | 22·6 | 20·7 | 91·6 |
| Sunn . . . | 1·15 | 1·09 | 94·8 | 21·5 | 18·9 | 87·9 |
| *Patada shevra* . | 1·10 | 1·17 | 106·4 | 22·2 | 21·5 | 96·8 |

The carbon contents of the soil in all treatments except cotton and *patada shevra* are showing slight decreases from the original but the changes are generally not so pronounced for any definite conclusions to be drawn. However, the tendency for lowering in carbon in the treatments fallow and sunn

requires mentioning and is again an indication of rapid oxidation of the organic matter which was added much earlier in these cases than in *patada shevra*. This corroborates the observations on the humus content. With regard to the modification of the C/N ratios by the different treatments, it may be seen that fallow and sunn have appreciably lowered the ratio. This may be taken to be a favourable indication of their effects. The C/N ratio under *patada shevra* has shown only a slight decrease and it is likely that this is due to incomplete oxidation of the organic matter which was incorporated, as has been stated above, much later than in sunn and fallow.

It may be worthwhile, in passing, to mention about the actual values of the C/N ratios obtaining in these soils. This ratio is considered to be about 10 to 12 in normal fertile soils, in comparison with which the ratios reported here will seem to be too high. The question of a certain amount of variation in the ratio in different climatic regions has been discussed by Russell [1937] wherein he has quoted figures obtained by McLean for Transvaal black loam as 14·4. Recently, Hosking [1935], when comparing the properties of the Australian black earths with the *regur* of India has reported variations between 13·5 to 18·5 for Australian soils and 8·3 to 21·3 for *regur*. Further corroboration is available for high ratios in the latter soils from the work of Sahasrabuddhe [1929], from whose figures for carbon and nitrogen for a typical black soil in the Poona district, the C/N ratio on calculation is found to give a figure of 23·0.

*Effects of different rotational treatments*

The effects of the general soil conditions, particularly of tilth, left after the various rotational treatments were closely observed on a crop of cane, planted soon after the completion of the studies described above. The choice of a suitable variety for this experiment presented a matter for some thought. It was felt that it would be desirable to have a variety which would withstand the effects of vagaries of the climate and thus be sure of completing a successful growth period, but which at the same time would fairly reflect in its growth and behaviour the effects of the treatments. From these points of view the choice fell on Co 419 which had also the advantage that it was being generally adopted in the canal areas and, therefore, it was believed that the results of this experiment would possess a fairly wide applicability.

The cane was grown according to the standard method of cultivation which was recommended at that time by the station, the main features being a 4 ft. spacing between rows, 10,000 setts (of three eye-buds each) per acre, and 150 lb. nitrogenous top-dressing half as S/A and half as cake, given in three equal doses of nitrogen at three and eight weeks after planting and finally at earthing up, about 4½ to 5 months after planting. No basal dose of manure was given to any of the treatments. It is of course usual that where the land has been green manured, no basal dose of manure is applied, but in the present experiment it was purposely withheld even in the other treatments in order to avoid the interference of the treatment effect by the manure.

The rapidity of germination of cane was the first observation to be taken as a factor most readily susceptible to the condition of soil tilth. The results are shown in Table VII where the treatments have been arranged in

descending order of their tilth and the corresponding germination at three and eight weeks respectively after planting shown against them.

TABLE VII

*Germination of cane after different rotational treatments*

| Treatment | Tilth before cane planting (single value index) | Germination (per cent) | |
|---|---|---|---|
| | | Three weeks after planting | Eight weeks after planting |
| *Patada shevra* . . . | 276 | 48·0±1·343 | 71·0±1·378 |
| Fodder *jowar* . . | 253 | 48·7±1·475 | 69·8±1·396 |
| Cotton . . . | 243 | 46·1±1·691 | 72·0±1·138 |
| Groundnut . . | 238 | 46·1±1·425 | 70·7±1·096 |
| Fallow . . . | 195 | 46·1±1·911 | 73·1±1·143 |
| Sunn . . . | 184 | 36·9±1·424 | 69·5±1·160 |

It may be observed from Table VII that the trend of the germination at three weeks is a fair reflection of the tilth. For, leaving aside the figures for *jowar* and fallow, *patada shevra* has given the highest germination, followed by cotton and groundnut, where evidently minor differences in soil tilth have not caused any outstanding differences in germination. The striking result is the poor germination in sunn which had comparatively inferior tilth. It must be, however, explained here that ordinarily a simple interpretation of this kind of the germination of cane is beset with difficulties due to unevenness of planting but special precautions such as proper selection of seed material etc. were taken to ensure that the conditions of planting were made as uniform as possible [Rege and Wagle, 1939]. The germination at the end of eight weeks has, however, nearly equalized in all cases showing that the tilth condition was only effective in promoting a quicker initial germination. Russell and Mehta [1938] found similar results when studying the effect of seed-beds produced by different cultivation implements on the germination of wheat. They observe: 'The germination on the roto-tilled plots was more rapid than on the other treatments studied for the first few days. Then the other treatments usually catch up, and when germination is complete there is no systematic difference in favour of any treatment.'

During this time when the cane was germinating the growth and vigour of the seedlings was closely watched and from the time when the cane had fairly established itself in all the treatments it was apparent even from visual examination that the seedlings in treatments which had better tilth were more vigorous and showed a better stand than in treatments which had inferior previous tilth. Quantitative determinations based on the weights of the seedlings were then started from a period of ten weeks after planting.

These latter observations on the growth of cane consisted of taking the weights of plants cut from a 2 ft. length of row from each plot at certain important stages of the crop growth. These strips were selected to represent the average growth of plants over the whole plot and, after exposing the setts by removal of the overlying soil, the plants were cut and immediately sent to the laboratory where they were weighed and a representative sample kept for moisture. The roots of the plants were separated, washed thoroughly to remove adhering soil, dried and weighed.

The shoot weights and root weights at different periods are shown in Table VIII.

It will be seen from the figures that, in the first period the shoot weight is highest in cotton, next in *patada shevra*, followed in somewhat close order by the other treatments. In *jowar*, the shoot weight is lowest among the treatments, and it may also be observed that sunn and fallow are much poorer than either cotton or *patada shevra*. In the second period of study, viz. 14 weeks after planting, cotton still retains its superiority but the margin is now narrower, the other treatments having made some headway. *Jowar*, however, continues to be the poorest among the treatments. A notable feature of the third period of study, which was taken first before earthing up is the progress made by sunn which is now highest in shoot weight and has even surpassed cotton. Fallow, however, has not made similar progress, while groundnut and *jowar* are now comparatively inferior among the treatments.

TABLE VIII

*Periodical weights of shoots and roots in cane after different rotational treatments*

(Dry matter in gm. in 2 ft. row lengths)

(Average of four observations per treatment)

| Treatment | 10 weeks after planting (16 April 1937) | | 14 weeks after planting (17 May 1937) | | 20 weeks after planting (26 June 1937) | |
|---|---|---|---|---|---|---|
| | Shoot weight | Root weight | Shoot weight | Root weight | Shoot weight | Root weight |
| Groundnut | 57·8 | 11·4 | 198·0 | 26·7 | 673·7 | 82·5 |
| Cotton | 89·2 | 15·9 | 262·3 | 36·8 | 823·9 | 110·3 |
| Fodder *jowar* | 50·8 | 13·3 | 177·3 | 26·8 | 670·6 | 91·1 |
| Fallow | 55·3 | 12·3 | 233·7 | 32·6 | 698·5 | 91·8 |
| Sunn | 60·0 | 11·7 | 195·4 | 28·0 | 848·2 | 119·3 |
| *Patada shevra* | 74·0 | 12·7 | 217·2 | 25·5 | 785·1 | 109·2 |

Regarding the weights of roots, at the first period, the weight is highest in cotton, and then in descending order, with small differences among themselves, being *jowar*, *patada shevra* and fallow. Sunn and groundnut are inferior. In the second period, cotton is still best with fallow, which has since moved up, a close second. The other treatments are more or less alike. In the third stage there is highest root development in sunn, followed by cotton and *patada shevra* which are nearly equal, the other treatments, particularly groundnut, being inferior.

Considering the relation which these two factors bear with the soil conditions, it may be stated that in the first stage the greater weights of both shoots and roots have been associated with the previous better tilth shown by the treatments, though not exactly in the same order. Cotton and *patada shevra* are especially prominent in this respect in both shoot and root weight while the condition under *jowar* has reflected only in a better root weight. This is probably the period when the physical condition of soil has a more pronounced effect on the plant growth under the present conditions of study. In the second stage we find that the green-manuring treatments which had the advantage of a higher level of fertility gradually making up and from this time onwards the effect of the soil tilth is masked by fertility factors. Of particular interest are the effects of cotton, which has encouraged cane growth much beyond what was expected from its condition of tilth and fertility, and in the third period of study, although sunn has surpassed it in total growth, it still remains superior to *patada shevra* and fallow. This order was more or less maintained in further growth observations like height, girth, etc. and in the final yield of cane.

The determination of soil tilth at periods corresponding to the above growth observations was attended with difficulties. The soil, even nine days after irrigation (i.e. just before the due date of the next irrigation) is usually too wet for the field-sieving method to be successfully employed. No other kind of any special apparatus, e.g. Tiulin's sieves for measuring the water-stable crumbs, was available. This has been adopted in our later studies. Other methods, more or less improvized or only just indicative of the general state of things, had to be adopted. During the first stage the distribution of irrigational water in the profile in 6 in. layers to a total depth of 2 ft. was determined on the assumption that a free and easy penetration would indicate a better physical condition or tilth of the soil. These results did not fulfil expectations and the most which could be said about them is that among the treatments only *patada shevra* and cotton showed a gradual gradient of moisture from the top to the lower layers and could thus be said to have retained their former good tilth.

At two subsequent periods the dispersion coefficient which was also done before cane planting and has already been described, was employed as an indication of soil structure. The results are shown in Table IX.

The attainment of a nearly uniform state of micro-structure even from the second period of our study (i.e. 14 weeks after planting) is shown by the first set of figures. The values at the later period (20 weeks) are also nearly equal but the general dispersion is slightly higher than at the former period,

TABLE IX

*Dispersion coefficient of soil at various periods of growth of cane after different rotational treatments*

(Averages of four separate determinations)

| Treatment | At 14 weeks after planting | At 20 weeks after planting |
|---|---|---|
| Groundnut | 59·78 | 62·42 |
| Cotton | 58·13 | 59·10 |
| Fodder *jowar* | 58·24 | 61·09 |
| Fallow | 59·38 | 62·74 |
| Sunn | 58·56 | 61·55 |
| *Patada shevra* | 58·47 | 64·46 |

These studies would appear to indicate that the soil structure under irrigation and cane growing tends to equalize whatever the previous treatment.

The ultimate effects of the different rotational treatments on the cane crop may be seen on the final yield of cane the figures for which, with other observations, are given in Table X.

TABLE X

*Harvest data of cane after different rotational treatments*

(Averages of four replicate plots)

| Treatment | Yield per acre | | Calculated weight per cane in lb. | Purity of juice per cent |
|---|---|---|---|---|
| | Number of canes | Weight in tons* | | |
| Groundnut | 26,917 | 24·32 | 2·02 | 92·0 |
| Cotton | 30,782 | 28·85 | 2·10 | 89·3 |
| Fodder *jowar* | 28,083 | 26·76 | 2·13 | 91·5 |
| Fallow | 30,080 | 30·39 | 2·26 | 91·8 |
| Sunn | 32,873 | 32·68 | 2·23 | 90·7 |
| *Patada shevra* | 33,159 | 34·27 | 2·31 | 92·1 |

* Critical difference for significance 4·29 tons per acre

It is evident from the figures given in Table X that the yields of treatments fall into two groups, green-manuring and otherwise, the green-manuring treatments having finally established themselves as superior to the other treatments. In other words, the factors contributing to the fertility level of the soil have more than recompensed for the initial advantage obtained by some treatments due to superior tilth. Where both these factors were combined the yield has been the highest as in *patada shevra*. The order of yields is *patada shevra* > sunn > fallow > cotton > *jowar* > groundnut. The analysis of variance showed high significance for treatments. The critical difference for significance being 4·29 tons per acre, *patada shevra* is significantly superior to all except sunn and fallow (being very nearly so over the latter). Among the rotational crops, cotton stands out prominent as having had the best effect on the cane crop and is inferior statistically only to *patada shevra*. The order of yields generally agrees with that of the plant population and the weight per cane. It is of particular interest to note that in spite of higher number of canes in the green-manuring treatments in general, the weight per cane is also higher, showing the beneficial effects of higher available nitrogen (Table IV). The purity of juice, however, has not suffered on this account.

In summing up, it may be seen that the yields are well correlated with the initial nitrogen status of the soil. Referring back to Table V, it will be seen that in *patada shevra*, sunn, fallow and cotton which gave higher yields, both the actual nitrogen level as well as the extent of increase of the original by the treatment are higher, though not in the same order as of the yields. Conversely, in the treatments groundnut and *jowar*, it can be said that the nitrogen deficiency caused by them has been the main factor in depressing the cane yield. It was also pointed out that nitrate (Table IV) was higher in the green-manuring treatments indicating a higher level of available nitrogen before cane planting. It is likely that in these treatments the ready supply of available nitrogen continued during the life of the cane crop. With regard to other factors that may have induced better growth in the green-manuring treatments, the tendency to lower the C/N ratio (Table VI) is likely to have had a beneficial effect on the biological activities in soil favourable to plant growth. The available phosphoric acid was also determined before and after some of the rotational treatments in the expectation that this would throw some light on the behaviour of cane yields but the figures did not show any consistency.

*Soil condition after completion of one rotational cycle*

After the harvest of the cane crop soil tilth was again determined to see the condition left after the completion of the rotational cycle. Field-sieving was done as before but as it was thought that the cane roots which are fairly extensive might interfere with the sieving, the tilth was separately determined within the root zone and away from it, the figures for which and those for the corresponding moisture contents are shown in Table XI.

It will be observed that in spite of differences in moisture content the tilth figures are fairly close. It is likely that the whole of the soil mass must have been reduced to the same condition of tilth by cane growing and later the soil away from the root zone, i.e. near the surface and in the intervening

TABLE XI

*Comparative figures for soil tilth and corresponding moisture contents after cane within and without the root zone*

(Averages of 40 separate determinations per treatment)

| Treatment previous to cane | Within the root zone | | Without the root zone | |
|---|---|---|---|---|
| | Single-value index for tilth | Moisture (per cent) | Single-value index for tilth | Moisture (per cent) |
| Groundnut | 222 | 21·7 | 207 | 16·0 |
| Cotton | 229 | 20·6 | 232 | 15·4 |
| Fodder *jowar* | 242 | 19·3 | 258 | 17·2 |
| Fallow | 212 | 20·8 | 217 | 14·9 |
| Sunn | 206 | 21·2 | 217 | 16·3 |
| *Patada shevra* | 227 | 21·3 | 226 | 16·4 |

spaces between the cane rows must have dried to a lower moisture content. It is noteworthy that, though the soil had attained the same state of micro-structure as shown by the dispersion coefficient during cane growth, the trend of the present figures is not very dissimilar from that before cane planting. That is, treatments *jowar*, cotton and *patada shevra* are in a group showing more or less better tilth while fallow and sunn are still inferior from this point of view. Either the treatment of agitation that the soil undergoes during the determination of dispersion coefficient is so drastic as to reduce the soil to the same micro-structure or, the soil, after partial drying, has taken up a field alignment of soil particles similar to that before cane planting. This aspect will be probably clarified when the determination of water-stable crumbs which are in progress at present is completed. At the same time it may be noted that the differences between the various treatments tend to narrow down after cane growing. Another remarkable result is that, after the drastic treatment, particularly by way of frequent heavy irrigations, the soil has undergone during cane growing, the tilth has remained at a comparatively high figure in all the treatments, having actually increased in fallow and sunn.

*Changes in the micro-structure due to cane growing*

While considering these changes in the summation figures (single-value indices) for soil tilth from time to time it would be worthwhile to go into the details of the changes which the various fractions have undergone. Accordingly, the average summation figures for tilth immediately after the harvest

f the *kharif* crops in 1936, those just before cane planting in January 1937 nd, finally after the harvest of cane in March 1938, with the proportions f the different soil aggregates on each occasion are given in Table XII.

TABLE XII

*Results of aggregate analysis of the soil, after harvest of* kharif *crops, before cane planting, and after harvest of cane*

(Averages of 80 separate determinations per treatment)

| Treatment | First fraction > 1½ in. | Second fraction >5/8 in. | Third fraction > 1/4 in. | Fourth fraction >3 mm. | Fifth fraction > 3 mm. | Average summation figure | Critical difference for significance (P= ·05) |
|---|---|---|---|---|---|---|---|
| | Percentages of total weight of soil | | | | | | |
| Groundnut— | | | | | | | |
| *a* | 51·9 | 17·5 | 12·0 | 12·7 | 4·6 | 235 | |
| *b* | 63·3 | 15·7 | 7·2 | 7·0 | 6·7 | 238 | 14·4 |
| *c* | 59·1 | 21·0 | 8·0 | 6·5 | 5·4 | 207 | |
| Cotton— | | | | | | | |
| *a* | 64·0 | 13·8 | 8·1 | 8·7 | 5·2 | 217 | |
| *b* | 63·3 | 16·4 | 6·9 | 6·4 | 7·0 | 243 | 13·9 |
| *c* | 54·1 | 24·0 | 8·7 | 7·1 | 5·9 | 232 | |
| Fodder *jowar*— | | | | | | | |
| *a* | 66·8 | 13·0 | 7·2 | 6·8 | 6·1 | 223 | |
| *b* | 64·2 | 15·4 | 6·4 | 6·2 | 7·8 | 253 | 19·6 |
| *c* | 51·2 | 23·9 | 9·2 | 8·1 | 7·0 | 258 | |
| Fallow— | | | | | | | |
| *a* | 62·6 | 13·0 | 9·1 | 9·5 | 5·1 | 221 | |
| *b* | 68·0 | 15·3 | 6·3 | 5·5 | 5·0 | 195 | 14·6 |
| *c* | 54·8 | 24·5 | 8·6 | 6·6 | 5·4 | 217 | |
| Sunn— | | | | | | | |
| *a* | 67·9 | 13·3 | 7·7 | 7·1 | 3·9 | 183 | |
| *b* | 70·3 | 14·0 | 5·9 | 5·2 | 4·6 | 184 | 13·2 |
| *c* | 57·8 | 21·2 | 8·6 | 6·6 | 5·5 | 217 | |
| *Patada shevra*— | | | | | | | |
| *a* | 60·4 | 12·3 | 8·7 | 10·5 | 7·9 | 280 | |
| *b* | 58·7 | 16·9 | 7·6 | 7·7 | 9·1 | 276 | 21·8 |
| *c* | 55·3 | 22·0 | 8·8 | 7·2 | 5·8 | 226 | |

*a*= after harvest of *kharif* crops
*b*= before planting of cane
*c*= after harvest of cane

Considering the figures against '*a*' in Table XII, i.e. soon after harvest of the *kharif* crops, it can be seen that the order of tilth, according to summation figures, is *patada shevra*>groundnut>*jowar*, fallow, cotton >sunn. Regarding the proportion of different-sized aggregates in the different treatments, it may be observed that the fraction larger than 1½ in. (i.e. the fraction remaining on the first sieve) forms by far the largest portion. The differences in the final tilth figures appear to be due mainly to variations in the first and the last fractions. It may be remembered that, as the last fraction has to be multiplied by 20 to obtain its relative surface area even a small change in this fraction is liable to cause an appreciable variation in the summation figure. In *patada shevra* there is the highest proportion of the last fraction among the treatments and in sunn there is the lowest proportion of this fraction accompanied by the highest proportion of the first fraction.

The condition of tilth in January 1937 after the soil in these treatments has been left to the weathering action of the atmosphere, as well as that due to green manuring in those treatments (figures against '*b*' in the table) shows some interesting changes. Taking the summation figures, cotton and *jowar* show some improvement, fallow shows a slight decrease, there being no appreciable change in the other treatments. Regarding changes in individual fractions there is a general trend of comminution of the fourth fraction (indicated by decreases in this fraction) giving rise to an increase in the last fraction. This is, however, offset by an opposite tendency of the smaller particles to coalesce and form larger particles as shown by decrease of these particles (third and fourth) and an increase of larger particles (second). This movement in some cases extends up to the first fraction (1½ in.). The increase or decrease of the summation figure is determined by the extent of this counterbalancing.

The single-value figures for tilth, determined after the harvest of cane (figures against '*c*' in the table) show, as has been pointed out, a considerably smaller variation among the treatments than that prevailing before planting. The tilth in *patada shevra* and groundnut has shown decrease (also cotton to a slight extent) whereas fallow and sunn show some improvement. The changes in the fractions during the cane cropping are chiefly characterized by a very interesting trend, viz. that with the exception of fallow and sunn, the three central fractions tend to be built up by movements from both directions, by comminution of the largest fraction as well as the coalescence of the smallest. And as before, the summation figure depends on the extent of these two movements. In fallow and sunn the movement has been largely in one direction, that of comminution of the larger particles into the smaller, which has resulted in an increase of the summation figure. On the whole, the changes in the structure that are apparent under one cane crop are very encouraging in that they not only do not indicate any deterioration of tilth but, on the contrary, actually show a building up certain group of particles. Possibly this is due to the effect of the root system of the cane crop which, while it helps to break up larger clods by its extensive ramifications, also at the same time helps the formation of granules along its finer roots.

## Summary and conclusions

This paper deals with investigations regarding the effects of certain common *kharif* rotational crops and green-manure treatments on the soil and on a succeeding cane crop. The *kharif* treatments were : (1) cotton, (2) groundnut, (3) fodder *jowar*, (4) sunn-hemp, (5) *patada shevra* (a selected leguminous weed) and (6) fallow. The experiment was laid out on the randomized block method with four replicates on a typical black cotton soil at the Padegaon farm, and the main conclusions reached during this investigation are as follows :—

From a detailed soil examination done after disposal of the crops, soil tilth as measured by Keen's method of sieves showed the descending order of treatments, *patada shevra* > *jowar* > cotton > groundnut > fallow > sunn. Among properties examined which were likely to be related to tilth, the dispersion coefficient of soil showed a fair agreement, having an inverse relationship with tilth. Moisture showed good parallelism to the dispersion coefficient within a certain limit. The nitrate and bacterial number, however, did not show any relation with the tilth condition and were generally much higher in the green-manuring treatments (including fallow where weeds were buried in). Oxygen-giving power did not give consistent values. Among fertility factors nitrogen status was found to have been appreciably raised by *patada shevra* and sunn and to a small extent by cotton and fallow. No definite trend was noticeable in the humus contents, but the green-manuring treatments showed a tendency to lower the C/N ratios of the soil.

With regard to the effect of the rotational crops on the succeeding cane, it was found that the treatments with the better initial tilth induced a quicker germination although at the end the germination equalized under all treatments. The effects of tilth were also reflected to a certain extent in the weights of shoots and roots of cane up to a period of about 10 weeks after planting. After this period other factors slowly dominated, and the green manure treatments ultimately established themselves superior to others.

Soil examination, done at the same periods when the growth observations were taken, showed that the dispersion coefficient was almost equal for all treatments from the period of 14 weeks after planting, indicating the attainment of an equal value for soil structure in all treatments.

The final yields of cane were definitely associated with better fertility, being in the order of *patada shevra* > sunn > fallow > cotton > *jowar* > groundnut. Statistical analysis showed high significance for treatments and that *patada shevra* was significantly superior over all the treatments except sunn and fallow (nearly so over the latter). The yield after cotton was very promising as it was highest among the rotational crops and only *patada shevra* was significantly superior to it. *Jowar* and groundnut proved to be much inferior to cotton under these conditions.

Finally, quantitative studies on soil tilth indicate that cane growing actually improves the field soil structure by building up certain desirable groups of soil aggregates. It is suggested that the beneficial effect of cane growing on the soil tilth may be due to the extensive root system of sugarcane.

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# PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

## IV. MINERAL NUTRITION : (A) PHOSPHATES

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(Received for publication on 8 May 1942)

(With four text-figures)

### Introduction

In the Deccan canal tract, sugarcane is an irrigated crop and is manured heavily with nitrogenous top-dressings consisting mainly of sulphate of ammonia and safflower, groundnut or castor-cakes. The soils, being deficient in nitrogen, the crop invariably responds to these manures quite perceptibly and consequently the cultivation of sugarcane involves a large expenditure on these nitrogenous manures alone. In any investigation in the mineral nutrition of sugarcane, therefore, nitrogen stands pre-eminent requiring the first attention and we have accordingly concentrated our researches on this element the results of which will be described in a separate paper.

In any systematic studies on the optimum absorption of individual element by the plant, it would be necessary to have for comparison a plant of the same species under conditions of balanced nutrition. While the experimental evidence from the various workers in this field is rather conflicting, making it impossible to put forth any definite generalizations, it is apparent that there exists for each plant species a physiologically balanced nutrient solution from which normal absorption occurs, resulting in the greatest growth and yield. A departure from this balance, either through deficiency or excess of any one element will produce a disturbance in the absorption of different elements which may exert profound effects on metabolism. The researches in the nutrition of any one element by the plant would thus require the initial determination of the availability of other elements in the soil in order to prevent any unbalanced nutrient supply to the plant and as the main aim of our investigation was to determine the nitrogen nutriment of sugarcane, it was considered quite essential to initially test the soil under experimentation for the availablity of the other two important manurial constituents, viz. phosphate and potash.

* This scheme is partly subsidized by the Imperial Council of Agricultural Research

The soils of the Deccan canal tract belong to the broad group of *regur* or black cotton soil, which is further recently classified into distinct soil types according to the genetic system of soil classification by Basu and Sirur [1938]. Two of these soil types, viz. B and F are existent on the farm, the major area being under the former type. The type F is very shallow, the average depth being about 15 in., while the other type possesses a depth varying from 3 ft. to 12 ft. For the individual characteristics of these types, the original paper referred to above may be consulted. The chemical analysis of these soil types for both the total and available phosphate and potash could not, however, be properly interpreted as regards the deficiency or otherwise of these minerals owing to the absence of any further information about their limiting figures for sugarcane in these types as is now collected, for instance, for the Hawaiian soils. In order to get immediately a definite idea about the state of these constituents in the soil under experimentation, it was, therefore, considered advisable to study the effect of the application of potassic and phosphatic fertilizers on the cane growth directly in the field.

## Outline of the scheme of work

At the outset, a small-scale experiment with duplicate plots only was laid out during the season of 1933-34 with both the potassic and phosphatic fertilizers in the soil type B which was selected for the detailed studies in the nitrogen nutrition of sugarcane. A top-dressing of 150 lb. N in equal proportions of sulphate of ammonia and safflower-cake as recommended in the standard Manjri method [Bombay Dept. of Agric., Leaflet No. 17 of 1929] was common to all the three treatments. One of these treatments received in addition 100 lb. $P_2O_5$ in the form of superphosphate and the other 100 lb. $K_2O$ in the form of sulphate of potash as basal manuring, the third treatment being the control receiving no basal manuring. The results are given in Table I.

### Table I

*Comparative studies in the effect of phosphatic and potassic treatments*

(Variety Pundia ; Date of planting 17 January 1933 ; Date of harvest 11 January 1934)

| Treatment | Germination at eight weeks (per cent) | Number of canes per acre | Calculated yield per acre in tons | Weight per cane | Brix on 26 September 1933 | Brix on 11 January 1934 |
|---|---|---|---|---|---|---|
| Control—150 lb. N alone | 57·9 | 28133 | 34·8 | 2·77 | 11·9 | 16·0 |
| 150 lb. N + 100 lb. $P_2O_5$ | 63·9 | 33578 | 43·7 | 2·85 | 12·2 | 16·9 |
| 150 lb. N + 100 lb. $K_2O$ | 62·3 | 29040 | 36·3 | 2·80 | 11·5 | 16·2 |

These results clearly reveal the deficiency of phosphate in the soil. Its effect seems to be mainly on the number of canes. The weight per cane is practically similar in all the treatments and the higher tonnage obtained in the one receiving phosphatic manuring is, therefore, mainly due to the presence of a large number of canes at the harvest time. The figures for brix also indicate

a tendency towards the early attainment of maturity in this treatment. On the other hand, there has been practically no variation from the control in the behaviour of the crop with potassic manuring which clearly suggests the sufficiency of the potash in the soil. Any further investigation in the potassic manuring was, therefore, stopped, while the finding about the beneficial effect of the phosphatic manuring was critically tested in a large scale replicated experiment with the same sugarcane variety and under the same nitrogenous treatment by the agricultural section for two consecutive seasons of 1934-35 and 1935-36. During the first season, the phosphatic treatment gave 43 per cent higher tonnage showing a very high significance. The results were not so very outstanding during the second season, mainly due to the unfavourable climatic conditions during the grand period of growth. In spite of this, this treatment gave 15 per cent higher yields which just approached the statistical significance. Similar trial by the Soil Physicist in the soil type F with POJ 2878 and with a higher nitrogenous dose of 300 lb. N applied only in the form of sulphate of ammonia gave almost double the yield in the case of the phosphatic treatment. These statistical trials have thus confirmed the preliminary observation about the phosphatic deficiency in the soil under investigation and as a result, the application of a basal dose of 100 lb. $P_2O_5$ was introduced in all our major field trials in the nitrogen nutrition of sugarcane.

As the necessity of phosphatic manuring was definitely established, the next course was to determine the suitable times of its application both from the standpoint of its action on the plant development and maturity, and also the period for which the effect of superphosphate once applied continued. Besides the developmental studies, this naturally required detailed investigations in the uptake of nutrients by periodical sampling, and, therefore, a special experiment was laid out for the purpose during the season of 1937-38 and was also repeated in the next year. During the first season, the block selected for the experiment had received no phosphatic manuring any time previously, while the next year's experiment was shifted to a similar block which had received the phosphatic application for the previous crop of sugarcane during the season of 1935-36, the underlying idea being to see whether the effect of the previous application of 100 lb. $P_2O_5$ in the form of superphosphate continued even in the fourth year of cropping. The rotation followed in these blocks was sunn, sugarcane and cotton, the first being ploughed in August for the next crop of sugarcane. POJ 2878 was selected as the sugarcane variety as it occupied the major area under the canal tract.

The manurial treatments consisted of (1) a top-dressing of 300 lb. N with and without an initial application of 100 lb. $P_2O_5$ in the form of double superphosphate and (2) top-dressings of 450 and 600 lb. N with and without 50 lb. $P_2O_5$ at earthing in addition to the initial dose of superphosphate at the rate of 100 lb. $P_2O_5$ common to all. The first series was intended to determine the effect of phosphate on the plant development and the second its influence on maturity which was found to be greatly delayed in the case of heavy nitrogenous manuring. These treatments were slightly modified during the next season by eliminating the one of 600 lb. N as this dosage was found to be far in excess of the crop requirement without any advantage in the production of cane and

instead, substituting the one of 100 lb. $P_2O_5$ without any nitrogenous top-dressing. In order to prevent the high concentration of nitrogen in the soil solution with such heavy top-dressings, the proportion of sulphate of ammonia to cake was kept to 1 : 2 with four times of application during both the years instead of 1 : 1 with three times of application as recommended in the standard Manjri method. There were duplicate plots for each treatment, the plot size being 28 ft. × 38 ft. with seven rows 4 ft. apart.

## Presentation of the data

### *Developmental studies*

*Germination.* Planting was done by mid-January in both the years at the rate of 10,000 three-budded setts per acre. Before planting, double superphosphate was added at the rate of 100 lb. $P_2O_5$ per acre with one-tenth of the total dose of nitrogenous top-dressing in the form of sulphate of ammonia only to all the phosphatic treatments except the no-nitrogen one which did not receive any nitrogen. The control treatment received only sulphate of ammonia. The results (Table II) clearly reveal that from the standpoint of germination, there is practically no advantage from the phosphatic manuring. On the other hand, there is an indication of the slight lowering in the rate of germination due to phosphatic manuring during both the seasons although the effect is not significant. In the case of the treatment P, however, there is a significant fall in the rate up to three weeks which clearly brings out the influence of nitrogen. Later on the differences between the treatments are greatly narrowed down. The acceleration of the germinative activity with the application of sulphate of ammonia at planting has already been described by Rege and Wagle [1939]. During the season of 1938-39, counts were not taken at eight weeks as tillering had already started after six weeks.

TABLE II

*Periodical data of germination*

(Per cent of the total buds planted)

(Variety POJ 2878; Average of all rows per plot excluding the end rows)

| Treatment* | 1937-38 | | | 1938-39 | |
|---|---|---|---|---|---|
| | Three weeks counts | Six weeks counts | Eight weeks counts | Three weeks counts | Six weeks counts |
| (1) N—Control—N 300 lb. N only | $36 \cdot 9 \pm 2 \cdot 25$ | $78 \cdot 7 \pm 1 \cdot 23$ | $78 \cdot 7 \pm 1 \cdot 17$ | $45 \cdot 5 \pm 2 \cdot 51$ | $83 \cdot 5 \pm 1 \cdot 38$ |
| (2) NP—300 lb. N + 100 lb. $P_2O_5$ | $33 \cdot 9 \pm 1 \cdot 75$ | $74 \cdot 4 \pm 1 \cdot 1$ | $78 \cdot 3 \pm 1 \cdot 49$ | $42 \cdot 1 \pm 0 \cdot 76$ | $82 \cdot 3 \pm 1 \cdot 49$ |
| (3) P—No nitrogen + 100 lb. $P_2O_5$ | ... | ... | ... | $36 \cdot 3 \pm 1 \cdot 3$ | $77 \cdot 5 \pm 0 \cdot 99$ |

*As the effect of nitrogen will be discussed in a separate paper the data are not given for the other nitrogenous treatments

*Tillering.* After the completion of the germination, periodical counts of the total number of plants per row were maintained for two randomly selected rows per plot till the operation of earthing. The results are given in Table III after reducing the figures to 1 ft. length for convenience.

These observations could not be continued till harvest time owing to the periodical cutting of the plants for the uptake of nutrients, exudation, maturity tests, etc. In order to find out, therefore, the performance of the individual germinated bud throughout its life-cycle, 10 randomly selected mother plants per treatment were labelled for all the tillers formed from the beginning and their development was carefully noted monthly till harvest time (Table IV).

TABLE III

*Plant population per foot and per cent borer attack*

(Average of two rows per plot)

| Date of observation | 1937-38 | | | | 1938-39 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 300 N + No $P_2O_5$ N | | 300 N + 100 $P_2O_5$ NP | | 300 N + No $P_2O_5$ N | | 300 N + 100 $P_2O_5$ NP | | No N + 100 $P_2O_5$ P | |
| | Plant population | Per cent borer attack | Plant population | Per cent borer attack | Plant population | Per cent borer attack | Plant population | Per cent borer attack | Plant population | Per cent borer attack |
| 18 March | 2·2 | ... | 2·3 | ... | 5·7 | 0·23 | 5·2 | 0·0 | 4·4 | 1·04 |
| 4 April | 4·2 | 2·3 | 6·2 | 1·3 | 5·9 | 0·89 | 6·2 | 1·6 | 6·5 | 1·80 |
| 19 April | 5·4 | 2·3 | 7·2 | 1·9 | 7·4 | 6·10 | 7·2 | 3·9 | 7·4 | 5·20 |
| 5 May | 6·4±0·24 | 4·6 | 8·4±1·54 | 1·9 | 7·2±0·84 | 5·70 | 7·8±1·36 | 5·7 | 7·4±0·54 | 9·10 |
| 5 June | 5·7 | 5·0 | 7·1 | 3·5 | 5·1 | 8·60 | 5·3 | 10·3 | 5·1 | 8·10 |
| 21 June | 4·9 | ... | 6·5 | ... | 3·8 | 10·80 | 3·3 | 12·5 | 3·2 | 8·10 |

TABLE IV

*Plant population in 10 random stools*

| Date of observation | 1937-38 | | 1938-39 | | |
|---|---|---|---|---|---|
| | 300 N + No $P_2O_5$ N | 300 N + 100 $P_2O_5$ NP | 300 N + No $P_2O_5$ N | 300 N + 100 $P_2O_5$ NP | No N + 100 $P_2O_5$ P |
| 18 March (mother canes) | 10 | 10 | 10 | 10 | 10 |
| 16 April | 30·0±2·05 | 42·0±2·5 | 28·0±5·4 | 28·0±4·15 | 41·0±3·8 |
| 16 May | 33·0 | 34·0 | 26·0 | 27·0 | 32·0 |
| 18 June | 27·7±2·7 | 31·0±1·9 | 24·0±2·7 | 19·0±3·3 | 24·0±2·2 |
| 16 July | 19·0 | 26·0 | 20·0 | 17·0 | 19·0 |
| 15 August | 18·0 | 26·9 | 20·0 | 17·0 | 19·0 |
| 16 September | 18·0 | 26·0 | 19·0 | 17·0 | 19·0 |
| 17 October | 18·0 | 26·0 | 19·0 | 17·0 | 17·0 |
| 15 November | 16·0 | 26·0 | 19·0 | 17·0 | 15·0 |
| 15 December | 1 6·0±2·6 | 26·0±2·05 | 19·0±2·6 | 17·0±2·46 | 14·0±2·4 |
| 15 January | 17·0 | 26·0 | 19·0 | 17·0 | ... |
| Per cent successful plants | 48·8 | 61·7 | 54·3 | 60·7 | 34·1 |

The comparison of the figures of the plant population for the season of 1937-38 reveals a higher tillering activity in the phosphatic-treated plots. There is also an early start in tillering which eventually leads to the higher success at harvest time (Table IV) as the early-formed tillers are generally found to escape the borer attack to a much greater extent. Similar results of increased tillering by phosphatic manuring have also been obtained by Brenchley [1929] in her water-culture experiments with barley. This effect is not, however, evident during the next season of 1938-39. Only in the case of treatment P there is some indication of increased tillering when the individual stools are considered (Table IV). Owing to the deficiency of nitrogen, however, a great majority of the tillers so formed suffered death greatly lowering the percentage success in the end.

*Borer.* The ravages of the stem borer were determined in the same rows selected for tillering counts by cutting the borer-affected plants at the time of tillering counts and counting their number. The data are given in Table III as percentage of the total population along with that of plant population. The less intensity of borer attack as a result of phosphatic manuring is quite apparent, the more so during the season of 1937-38 than in 1938-39. The reason for this variation is explicit in the previous treatments of the block already referred to. Further comparative studies of the figures for the two years indicate that on the whole its ravages are more severe during 1938-39 than in the previous one. This would be an important contributory factor in the lowering of the number of canes and tonnage per acre which are observed during the latter year (Table VI).

*Growth.* This has been periodically measured by two methods. In the first case complete botanical observations such as total height, height of millable cane, number of mature and immature internodes and circumference were taken monthly beginning from the third month after planting on all the plants in the 10 stools labelled for tillering. The methods are the same as already described by Rege and Wagle [1939]. These data are averaged per plant and are given in Table V. In the second method, the crop was harvested periodically at definite stages in growth and fresh weights of stems and green leaves were determined separately. For this purpose, two end rows and 4 ft. on either side of the intermediate rows were excluded from sampling in order to avoid the border effect. The remaining lengths of the rows were then divided into 3 ft. strips from which only alternate strips were earmarked for sampling by random selection. By this method there was no possibility of any of the selected strips abutting on the previously sampled ones. As sampling error was found to be very high during early stages, eight strips were utilized for sampling at these periods, the number being reduced to six later on. These data are given in Table VI.

It would be evident from the inspection of both these tables that during the season of 1937-38 when phosphate was applied for the first time, its beneficial effect was not restricted to the tillering phase alone but was even visible during the greater part of the growth phase. For instance, both in the case of total height and the height of millable cane, the advantage of the basal dose of phosphate (Table V, series I) was quite pronounced till mid-August and it was only after this period that the treatment of nitrogen alone had shown an

## Table V

*Periodical botanical data per plant*

(Average of 10 random stools)

| Date of observation | 1937-38 | | | | | | 1938-39 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total height in inches | | Height of millable cane in inches | | Ratio of millable to non-millable cane height | | Total height in inches | | | Height of millable cane in inches | | | Ratio of millable to non-millable cane height | | |
| | N | NP | N | NP | N | NP | N | NP | P | N | NP | P | N | NP | P |
| *Series I* | | | | | | | | | | | | | | | |
| 17 April | 6·7± 0·6 | 8·3± 0·34 | ... | ... | ... | ... | 8·3± 0·4 | 8·5± 0·7 | 7·4± 0·4 | ... | ... | ... | ... | ... | ... |
| 16 May | 12·2 | 15·3 | ... | ... | ... | ... | 16·7 | 16·4 | 14·2 | ... | ... | ... | ... | ... | ... |
| 20 June | 26·6± 1·8 | 36·1± 3·07 | ... | ... | ... | ... | 39·9± 2·7 | 38·3± 2·2 | 26·8± 2·3 | ... | ... | ... | ... | ... | ... |
| 17 July | 34·5 | 46·6 | ... | ... | ... | ... | 55·3 | 54·6 | 30·6 | ... | ... | ... | ... | ... | ... |
| 16 August | 59·4± 1·8 | 67·1± 1·99 | 47·5 | 57·5 | 0·25 | 0·17 | 74·5± 1·9 | 78·0± 1·9 | 48·7± 3·1 | 58·4 | 60·8 | 39·6 | 0·25 | 0·28 | 0·23 |
| 15 September | 80·4 | 82·3 | 69·9 | 73·8 | 0·15 | 0·12 | 104·8 | 97·6 | 64·5 | 85·4 | 83·1 | 56·2 | 0·23 | 0·17 | 0·15 |
| 16 October | 120·2± 5·7 | 117·6± 6·6 | 97·7 | 97·0 | 0·23 | 0·20 | 149·3± 4·2 | 148·0± 0·6 | 103·7± 2·1 | 108·4 | 110·1 | 65·7 | 0·34 | 0·34 | 0·58 |
| 17 November | 144·2 | 136·1 | 101·4 | 102·5 | 0·42 | 0·33 | 163·0 | 159·9 | 112·1 | 115·5 | 116·2 | 79·6 | 0·41 | 0·38 | 0·41 |
| 15 December | 146·1 | 142·2 | 107·9 | 109·2 | 0·36 | 0·30 | 165·7± 6·2 | 164·2± 3·2 | 126·5± 8·9 | 125·3 | 125·6 | 87·5 | 0·32 | 0·31 | 0·46 |
| 16 January | 146·4 | 147·4 | 108·4 | 112·9 | 0·3[illegible] | 0·31 | 166·0 | 164·6 | ... | 127·2 | 126·8 | ... | 0·31 | 0·30 | ... |

## Table VI

*Periodical weight per plant*

(Average of random eight 3-feet strips till June and six later)

| Treatment | 1937-38 | | | | | | | | | | | | 1938-39 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mid May* | Mid-June | | | Mid-October | | | †Harvest time | | | Canes per acre | | Mid* May | Mid-June | | | Mid-October | | | †Harvest time | | | Tons per acre | Number of canes per acre |
| | L+St | L | St | L/St | L | St | L/St | L | St | L/St | Tons | No. | L+St | L | St | L/St | L | St | L/St | L | St | L/St | | |
| *Series I* | | | | | | | | | | | | | | | | | | | | | | | | |
| N—300 $N+No$ $P_2O_5$ | 120 | 273 | 254 | 1·07 | 474 | 1299 | 0·36 | 332 | 1451±113·4 | 0·23 | 46·1±3·57 | 32107 | 129 | 350 | 346 | 1·01 | 471 | 1658 | 0·28 | 288 | 1850±62·0 | 0·16 | 46·2±1·7 | 25410 |
| NP—300 $N+100$ $P_2O_5$ | 126 | 344 | 379 | 0·90 | 461 | 1350 | 0·34 | 295 | 1473±28·2 | 0·20 | 61·5±1·18 | 42108 | 179 | 362 | 357 | 1·01 | 460 | 1578 | 0·29 | 355 | 1766±48·1 | 0·20 | 49·2±1·37 | 28314 |
| P—No $N+100$ $P_2O_5$ | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 124 | 272 | 164 | 1·66 | 282 | 894 | 0·31 | 183 | 1236±148 | 0·15 | 25·2±3·18 | 20691 |
| *Series II* | | | | | | | | | | | | | | | | | | | | | | | | |
| NP—450 $N+100$ $P_2O_5$ | ... | 327 | 368 | 0·88 | 475 | 1567 | 0·30 | 324 | 1595±48·0 | 0·20 | 53·4±1·64 | 34122 | ... | 359 | 368 | 0·98 | 515 | 1665 | 0·31 | 301 | 1621±176·5 | 0·19 | 52·1±3·79 | 33396 |
| $N_2P$—450 $N+150$ $P_2O_5$ | ... | 296 | 344 | 0·86 | 416 | 1306 | 0·32 | 284 | 1550±72·6 | 0·18 | 49·4±2·29 | 32307 | ... | 275 | 277 | 0·99 | 498 | 1544 | 0·32 | 260 | 1729±289·5 | 0·15 | 51·6±6·2 | 29766 |
| NP—600 $N+100$ $P_2O_5$ | ... | 324 | 319 | 1·01 | 479 | 1419 | 0·34 | 328 | 1556±36·6 | 0·21 | 61·5±1·56 | 40293 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| $N_2P$—600 $N+150$ $P_2O_5$ | ... | 309 | 378 | 0·81 | 452 | 1372 | 0·33 | 335 | 1438±30·0 | 0·23 | 60·0±1·25 | 42108 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

L = Leaves
St = Stem
* There was no cane formation in May
† Harvesting was done in February except in no nitrogen+100 lb. $P_2O_5$ when it was done in January

acceleration of growth eventually attaining the same level of height as in the other one. The low ratio of millable to non-millable portion of cane in the phosphatic treatment is, in fact, suggestive of the slowing down of growth at later stage in this treatment. This is further confirmed by the periodical weights of millable canes as well as the ratio of these to green leaves (Table VI, series I). It would be seen that the weight per cane in the treatment of N has been throughout low till October and it is only due to later growth in this treatment that it has equalled the other one at harvest time. The weight of the functioning leaves is also higher at this period. As would be shown later, more than 50 per cent of the total uptake of nutrients is taken up during the rapid-growing period after earthing and it seems that as a result of less number of canes in this treatment, the competition between plants for the available nutrients is much less than in the other case. The higher rate of increase in growth per plant after earthing up in this treatment would be thus quite explicable. This acceleration of growth has not been, however, sufficient to make up for the reduction in the number of canes per acre and as a result there has been a distinct fall in tonnage in this treatment.

On the other hand, during the season of 1938-39, as in the case of tillering so also in the case of growth, the nitrogenous treatment has not shown any distinct beneficial effect of the basal dose of phosphate. The figures for heights (Table V, series I) as also of weights (Table VI, series I) are practically similar in both the treatments. The increase in the number of canes as well as tonnage per acre at harvest time are not also significant. These data, therefore, indicate an initial sufficiency of phosphate in the soil, the reason for which is already explained. In the case of the third treatment (No nitrogen + 100 lb. $P_2O_5$) unlike tillering, growth has suffered even from the beginning, clearly bringing out the importance of nitrogen for this phase in the life-cycle of the plant. There is not only a fall in height ; but both the number of mature internodes as well as circumference have also suffered. Otherwise in all other treatments, the data for these two items among botanical observations are practically similar even during the season of 1937-38 and as such these figures are omitted from Table V in order to keep its size within limited dimensions.

As regards series II, although it is primarily meant for finding out the effect of an additional dose of 50 lb. $P_2O_5$ applied at earthing on the maturity phase, its influence on growth as compared to the basal dose of 100 lb. $P_2O_5$ alone has also been studied by periodical botanical observations and green weight as in series I. The data, however, do not show any variation of sufficient magnitude between the figures for both heights of millable canes and plant weights owing to this additional dose and it seems, therefore, that this additional dose has not been of any advantage to the plant growth. It does not seem to be also far in excess of the amount required by the plant so as to produce a depressing effect on yield as observed by Russell [1923] and Wallace [1926] in other crops. In Table VI only the figures of plants' weights are given under series II while the figures of heights of millable canes are omitted in this case.

*Leaf area*. During periodical harvesting of plants for the determination of weights and mineral uptake, eight randomly selected green leaves per strip, i.e. 64 leaves during early stages and 48 later were taken per treatment for the measurement of their length and breadth.

The average product of these per leaf was taken for calculating the total leaf area per plant and on the strength of these data percentage variation in the different treatments from the control (N) was calculated. These results are given in Table VII.

TABLE VII

*Per cent variation in the leaf area from that of the control (N)*

(Based upon 64 randomly selected green leaves till mid-June and 48 later on)

| Periods | 1937-38 | 1938-39 | |
|---|---|---|---|
| | 300 lb. N + 100 lb. $P_2O_5$ | 300 lb. N + 100 lb. $P_2O_5$ | No N + 100 lb. $P_2O_5$ |
| Mid-May . . . . . | +17·5 | +35·4 | +53·7 |
| Mid-June . . . . . | +32·4 | +6·5 | —29·2 |
| Mid-October . . . . . | +4·4 | —2·5 | —43·5 |

The above figures clearly indicate the beneficial effect of phosphate at early stages during both the seasons. During the season of 1937-38, the effect continued practically throughout the life-cycle of the plant, while in the latter season it was only short-lived. The reason for this is already explained. The importance of nitrogen at later stages is clear from the data of the treatment P which received no nitrogen.

*Photosynthesis*. The rate of photosynthesis was determined on the top-most fully developed leaf of the crown directly in the field on the standing plant by the Ganong's punch method [1908]. This leaf was selected as it showed the highest rate of photosynthesis among all the green leaves. It is, no doubt, realized that this method does not represent the total weight of the product formed by photosynthesis during this period. Translocation of products from the leaf must be going on during this period, so also a certain amount of the product must be utilized in respiration which is proceeding simultaneously with photosynthesis. It may, therefore, be said to give the apparent rate of photosynthesis. None of the methods, however, devised for the measurement of photosynthesis can be considered to be quite satisfactory and this was specially selected as it enables one to work it conveniently under natural environmental conditions on the standing plant of such a height.

The results are given in Table VIII for the first series only. The superiority of phosphate during the season of 1937-38 is quite evident. Unfortunately these estimations were not continued during this season after mid-August and, therefore, the further effect of phosphate on this aspect of the plant behaviour remains unravelled. This can be, however, deduced from the growth phase of the crop discussed previously and if increase in weight can

be taken as the resultant effect of the photosynthetic activity of the plant, these figures for the rate of assimilation in these treatments would show a reverse order in later determinations.

The results for the season of 1938-39 for the above-discussed two treatments are practically similar. It is only in the case of the third treatment (No nitrogen + 100 lb. $P_2O_5$) in which a high rate of carbon assimilation is observed at both mid-May and mid-August with a fall later. Gregory and Baptiste [1936] have also reported high sugar content in leaves in their experiments with barley not receiving any nitrogenous manuring. They have explained this as due to high assimilation, low respiration, low protein synthesis and low meristematic activity. In the present case the tiller numbers are even slightly higher in this treatment (Table IV) and from this standpoint the meristematic activity cannot be said to be lower. No doubt in the case of increase in height per plant, there does seem to be slight decrease in this activity of the plant which would lead to decreased translocation; but on the whole, this would not account for such a large figure of per cent increase as obtained in this treatment for mid-May. The question of differential protein synthesis should also not arise as in this method the rate of assimilation would, in fact, reflect increase in total organic matter. Respiration is not determined and it would be, therefore, a moot point as to how far its decreased rate would be responsible for this high figure. For the present we shall have to be satisfied with attributing this high figure to two factors, viz. (1) high assimilation and (2) low respiration.

In the case of the second series, the figures for both the leaf area as well as carbon assimilation are fluctuating with no clear differentiation between the treatments and, therefore, owing to exigencies of space, the data are omitted from presentation.

TABLE VIII

*Rate of photosynthesis*

(Per cent increase in weight at 3 p.m. over samples taken at 8 a.m. by Gano's punch method)

(Average of 10 randomly selected plants)

| Treatment | Per cent increase in weight | | |
|---|---|---|---|
| | Mid-May | Mid-August | Mid-October |
| 1937-38 | | | |
| 300 N+No $P_2O_5$ . . . | 11·9 | 7·1 | .. |
| 300 N+100 $P_2O_5$ . . . | 16·7 | 13·7 | .. |
| 1938-39 | | | |
| 300 N+No $P_2O_5$ . . . | 5·71 | 6·3 | 11·3 |
| 300 N+100 $P_2O_5$ . . . | 5·10 | 8·5 | 9·0 |
| No N+100 $P_2O_5$ . . . | 26·90 | 9·4 | 2·2 |

*Root system.* The effect of phosphate on the development of roots has been studied in another experiment in an adjoining block with different forms of phosphatic manuring as superphosphate, bone meal and Nicifos, a nitrogenous top-dressing of 300 lb. N being common to all. These data have been already discussed in detail in a previous paper by Rege and Wagle [1941]. In general, it may be stated that except in the case of Nicifos, there is a favourable effect of phosphatic manuring on the root development. This is quite striking in the treatments of superphosphate and bone meal in which their quantities are applied in two equal doses of 50 lb. $P_2O_5$—one at planting and the other at earthing—while all the phosphate applied in one dose of 100 lb. $P_2O_5$ at planting in the form of superphosphate alone has not been so very effective. Nicifos has completely failed to produce a favourable effect on the root system.

*Flowering.* The data for flowering were collected at harvest time during the cutting of the strips for growth studies. This is given in Table IX.

TABLE IX

*Flowering data at harvest time*

| Treatment | 1937-38 | | | 1938-39 | | |
|---|---|---|---|---|---|---|
| | Total number of flowered plants | Total number of non-flowered plants | Per cent of flowered | Total number of flowered plants | Total Number of non-flowered plants | Per cent of flowered |
| *Section I* | | | | | | |
| 300 N + No $P_2O_5$ | 44 | 10 | 81·5 | 38 | 4 | 90·5 |
| 00 N + 100 $P_2O_5$ | 42 | 3 | 93·3 | 43 | 4 | 91·5 |
| No N + 100 $P_2O_5$ | ... | ... | ... | 33 | 1 | 97·1 |
| *Section II* | | | | | | |
| 450 N + 100 $P_2O_5$ | 48 | 13 | 78·7 | 29 | 19 | 60·4 |
| 450 N + 150 $P_2O_5$ | 25 | 34 | 42·4 | 28 | 20 | 58·3 |
| 600 N + 100 $P_2O_5$ | 25 | 36 | 41·0 | ... | ... | ... |
| 600 N + 150 $P_2O_5$ | 23 | 48 | 32·4 | ... | ... | ... |

It would be seen that during the season of 1937-38 the basal dose of phosphate has in the case of 300 lb. N led to the increase in flowering. This is quite in consonance with the growth behaviour in this treatment. On the other hand, the application of an additional dose of 50 lb. $P_2O_5$ at earthing besides the basal dose of 100 lb. $P_2O_5$ has led to the reduction in flowering in higher nitrogenous top-dressings as 450 and 600 lb. N. On the face of them these results seem to be quite contradictory. That they are not so will be shown when the mineral uptake will be discussed later. During the season of 1938-39, no such differences in flowering have been observed between the treatments in both the series.

*Maturity.* This is determined by the periodical brix and purity of the juice and all the results are given in Table X. The figures of brix are also graphically represented in Fig. 1. It would be seen that during the season of 1937-38, the figures for brix are higher in the phosphatic treatment from the start (mid-September) in series I. It is only at the end of February that the treatment of nitrogen alone has come equal to it, when both the treatments have shown the maximum brix attained during this season. The maximum purity is reached a fortnight later in both the treatments.

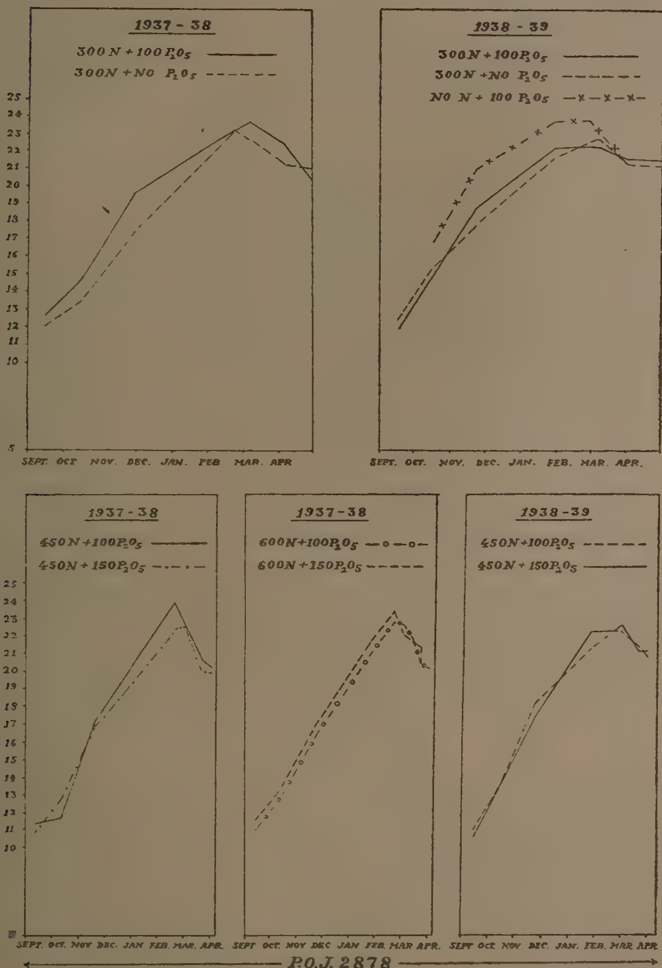


Fig. 1. Periodical brix data at 17·5°C.

There is further an indication of slower deterioration in the keeping quality of cane after the attainment of maximum brix in the case of phosphatic treatment than in the other one. During the season of 1938-39, the periodical data do not show such distinct delaying of the maturity in the case of nitrogen alone as was observed during the previous year. There is some slight beneficial effect of the phosphatic treatment which will not be, however, of economic value. Only the third treatment has shown the earliest maturity which can be ascribed to the deficiency of nitrogen. Other workers as Deer [1921], Cross [1925] and Sanyal [1928] have found the beneficial effect of phosphate from the standpoint of early maturity. It seems, however, that once there is

TABLE X

*Data of periodical brix and purity percentages*

| Treatment | 15 September | 15 October | | 23 November | | 27 January | | 23 February | | 9 March | | 8 April | | 18 April | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Brix at 17·5°C. | Brix at 17·5°C. | Purity per cent | Brix at 17·5°C. | Purity per cent | Brix at 17·5°C. | Purity per cent | Brix at 17·5°C. | Purity per cent | Brix at 17·5°C. | Purity per cent | Brix at 17·5°C. | Purity per cent | Brix at 17·5°C. | Purity per cent |
| 1937-38 | | | | | | | | | | | | | | | |
| *Series I* | | | | | | | | | | | | | | | |
| 300 N + No $P_2O_5$ . . | 12·1 | 13·5 | 70·5 | 18·4 | ... | 21·4 | ... | 23·4 | 88·91 | 22·6 | 92·0 | 21·3 | 90·3 | 21·0 | 88·6 |
| 300 N + 100 $P_2O_5$ . . | 12·7 | 14·7 | 72·1 | 19·5 | ... | 22·1 | ... | 23·4 | 89·32 | 23·5 | 94·0 | 22·3 | 92·8 | 20·3 | 91·1 |
| *Series II* | | | | | | | | | | | | | | | |
| 450 N + 100 $P_2O_5$ . . | 10·9 | 12·7 | 54·0 | 16·9 | ... | 20·9 | ... | 22·4 | 86·52 | 22·5 | 92·9 | 20·1 | 90·0 | 19·9 | 89·5 |
| 450 N + 150 $P_2O_5$ . . | 11·4 | 11·7 | 53·2 | 17·1 | ... | 21·9 | ... | 23·9 | 89·27 | 22·6 | 91·2 | 20·7 | 89·9 | 20·2 | 87·6 |
| 600 N + 100 $P_2O_5$ . . | 10·9 | 12·8 | 53·4 | 16·4 | ... | 21·2 | ... | 22·8 | 86·31 | 22·6 | 87·4 | 20·4 | 89·2 | 20·2 | 88·1 |
| 600 N + 150 $P_2O_5$ . . | 11·5 | 13·1 | 53·5 | 16·8 | ... | 21·7 | ... | 23·4 | 88·40 | 22·3 | 87·3 | 21·4 | 87·4 | 20·2 | 85·1 |
| 1938-39 | | | | | | | | | | | | | | | |
| *Series I* | | | | | | | | | | | | | | | |
| 300 N + No $P_2O_5$ . . | 12·5 | 15·4 | 71·4 | 17·8 | 81·4 | 21·6 | 91·4 | 22·6 | 89·1 | 22·9 | 90·8 | 21·3 | 90·3 | 21·2 | ... |
| 300 N + 100 $P_2O_5$ . . | 11·9 | 14·8 | 77·7 | 18·7 | 82·8 | 22·2 | 91·0 | 22·2 | 88·9 | 22·1 | 91·4 | 21·6 | 90·9 | 21·5 | ... |
| No N + 100 $P_2O_5$ . . | ... | 16·9 | 78·8 | 21·0 | 88·3 | 23·8 | 90·9 | 23·8 | 89·7 | 23·1 | 89·7 | 21·3 | 91·5 | ... | ... |
| *Series II* | | | | | | | | | | | | | | | |
| 450 N + 100 $P_2O_5$ . . | 10·7 | 13·4 | 58·0 | 18·0 | 81·1 | 21·3 | 91·7 | 22·2 | 86·8 | 22·3 | 92·9 | 21·3 | 90·0 | 20·8 | ... |
| 450 N + 150 $P_2O_5$ . . | 10·5 | 13·4 | 65·5 | 17·3 | 77·4 | 22·2 | 92·0 | 22·2 | 86·3 | 22·5 | 91·2 | 21·2 | 89·9 | 21·2 | ... |

a sufficiency of phosphate in the soil, an application of a basal dose of phosphate is not in any way effective in hastening the maturity further.

In the case of series II, the additional dose of 50 lb. $P_2O_5$ at earthing has shown some higher brix and purity during the early readings specially during the first year. The figures are not, however, of outstanding merit to be of economic value.

*Mineral nutrition*

The material from periodic harvestings of the different treatments was used for this investigation. In order to avoid any inconsistency in the analytical data owing to the translocation of the different constituents, the time of sampling was kept the same throughout. Immediately after weighment, average bulk samples of finely cut leaves and stems were kept for drying in a chamber at a temperature of about 60°C. After drying, these were finely powdered and stored for analysis. Care was taken to remove leaves from the plants as they dried and these were also taken for analysis separately in order to get a complete idea of the total removal of the mineral nutrients by the plant. The roots were not included in these studies, as the soil being a very heavy clay, the collection of roots free from clay particles was found to be impossible.

Besides the ultimate analysis of the material, sap from fresh samples of green leaves was analysed for different nitrogenous fractions. For these determinations, 100 gm. of average samples of leaves were immediately cut into small pieces. These were then crushed in a mortar after mixing with well-washed sand to break the cells and then pressed through a laboratory press at a definite pressure. The determinations of ammonia and nitrate were done immediately on the fresh sample while in the case of other fractions, the fresh material was autoclaved in order to kill the enzymatic activity and then taken for extraction of the juice as time permitted.

Standard A. O. A. C. methods of analysis were employed for the determination of nitrogen, phosphates, potash and calcium in dried material. In the case of leaf sap, ammonia was determined by steam distillation with magnesium oxide and the residual solution was utilized for the determination of nitrate by reduction with Devarda's alloy to ammonia. For the determination of crystalloid and total nitrogen, the method recommended by Richards and Templeman [1936] was followed. The material was thoroughly ground in a mortar with phenol water and filtered through paper pulp. In half the aliquot total nitrogen was estimated after previous reduction of nitrate with reduced iron. In the case of the other aliquot protein was removed with 50 per cent trichloracetic acid after filtering through chamberland filter. In the filtrate, total crystalloid nitrogen was determined also after previous reduction of nitrate with reduced iron.

*Water content of the leaf.* Instead of giving the actual figures of the water content of the leaf, these are represented in relation to the leaf area and dry weight of the leaves on the lines of Gregory and Richards [1929] in Table XI. Owing to heavy lodging of the crop as a result of late rains during the season of 1938-39, no reliable data could be collected about this at the time of harvest and, therefore, figures for this period are not given. It will be seen that both from the basis of unit leaf area as well as the dry weight, the water content of

the leaves in the NP treatment appears to be higher at the early stage of development (mid-May sample) during both the years. From the standpoint of the climate, this is the period when the plant is subjected to great stress owing to high temperatures and low humidity and when, as a result of these environmental conditions, the water requirement of the plant is found to be the highest. At this period practically all the varieties show incipient wilting while some of the varieties as Pundia and Co 419 even show the phenomenon of tip drying. The influence of phosphates in retaining the higher water content at this period both on the basis of leaf area and dry weight should therefore prove advantageous in the growth phase and this is, in fact, confirmed by the figures of increase in height as discussed previously. These data at later stages of growth do not show any consistent trend in both the years although there are indications of the fall in the water content in the phosphatic treatment during the season of 1937-38.

The ratios of dry weight to leaf area are also interesting in both these treatments as they clearly show that although the leaf area increases as a result of a basal dose of phosphate, there is not a proportionate increase in the dry weight. In other words the leaves get broader but thinner with the application of phosphate. Although chlorophyll was not determined in these treatments during these two seasons, its determination done during later years in similar treatments has shown it to be less throughout the growth phase in the phosphatic one than in the treatment receiving nitrogen alone. The higher rate of photosynthesis as a result of phosphatic application (Table VIII), however, suggests that both the lower dry weight as well as the lower chlorophyll content in the leaves do not in any way act as deleterious factors in this activity of the plant.

In the third treatment (P) the water content calculated on the basis of leaf area does not show the same trend as when calculated on the basis of dry weight. The latter practically agrees with the similar ratios for other treatments, while the former is much lower. These results indicate that for comparative studies the water content calculated on the basis of dry weight will be better than the other one. On the other hand, Gregory and Richards [1929] have shown the ratio of water content to leaf area to be better as it has given more consistent results in their experiments. Further work with a large number of treatments will be, therefore, necessary to elucidate this point.

*Uptake of mineral nutrients.* The data for N, P, K and Ca obtained on individual analysis of green leaves, dry leaves and stems were calculated and studied in more ways than one, e.g. per 100 gm. of each part of the plant, per 100 gm. of the whole plant, on whole plant basis as well as on acre basis. These results are illustrated graphically in Figs. 2, 3 and 4 for both the seasons. It would be seen that the percentage figures for the parts of the plant as well as the whole plant show a definite fall with the progress of growth, the largest fall being during the grand period of growth. Among the different organs the fall is generally more in the case of stems than in green leaves. This would be quite explicable on the basis of the relative increase in weight in these organs during this period. The curves for dry leaves clearly indicate that as the leaves dry, there is a translocation of nitrogen, phosphate and potash from these leaves to other parts, the highest translocation being in the case of phosphates. This rapid redistribution of phosphate seems to be the reason

### TABLE XI

*Water content of the leaf*

| Treatment | Mid-May | | | Mid-June | | | Mid-October | | | Harvest time | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Water / Leaf area | Water / Dry weight | Dry weight / Leaf area | Water / Leaf area | Water / Dry weight | Dry weight / Leaf area | Water / Leaf area | Water / Dry weight | Dry weight / Leaf area | Water / Leaf area | Water / Dry weight | Dry weight / Leaf area |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1937-38 | | | | | | | | | | | | |
| N—300 N + No $P_2O_5$ | 0·248 | 3·57 | 0·0358 | 0·233 | 4·37 | 0·0534 | 0·205 | 2·41 | 0·085 | 0·14 | 2·20 | 0·064<br>0·204 |
| NP—300 N + 100 $P_2O_5$ | 0·262 | 4·00 | 0·0300 | 0·220 | 3·96 | 0·0560 | 0·205 | 2·96 | 0·071 | 0·12 | 2·02 | 0·061<br>0·183 |
| 1938-39 | | | | | | | | | | | | |
| N—300 N + No $P_2O_5$ | 0·292 | 3·03 | 0·096 | 0·202 | 3·93 | 0·0607 | 0·210 | 2·57 | 0·082 | ... | ... | ... |
| NP—300 N + 100 $P_2O_5$ | 0·312 | 3·68 | 0·085 | 0·230 | 3·97 | 0·0580 | 0·215 | 2·80 | 0·077 | ... | ... | ... |
| P—No N + 100 $P_2O_5$ | 0·197 | 3·47 | 0·057 | 0·196 | 3·08 | 0·0810 | 0·194 | 1·94 | 0·100 | ... | ... | ... |

$\frac{\text{Weight of water}}{\text{Leaf area}}$ = gm. of water per sq. in. leaf surface

$\frac{\text{Dry weight}}{\text{Leaf area}}$ = gm. of dry weight per sq. in. leaf surface

$\frac{\text{Water}}{\text{Dry weight}}$ = gm. of water per gm. of dry weight

of the smallest amount of phosphate required by the plant. In the case of calcium no translocation during the process of drying is visible and this would explain the necessity of its continued uptake per plant till harvest time.

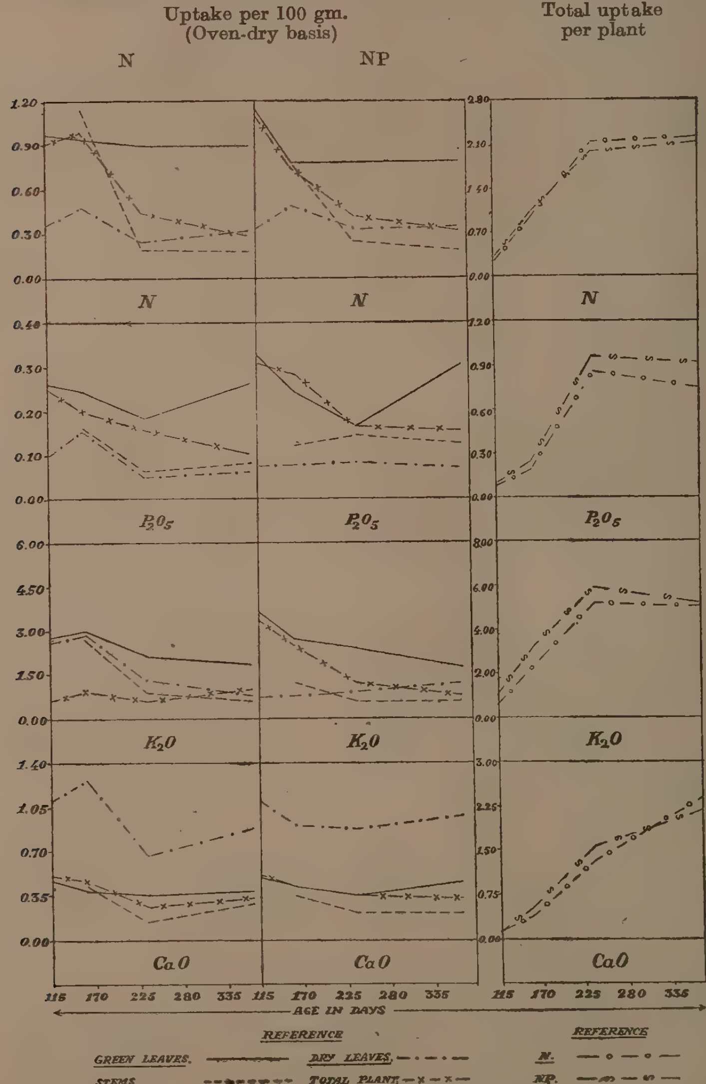


FIG. 2. Variety POJ 2878, 1937-38

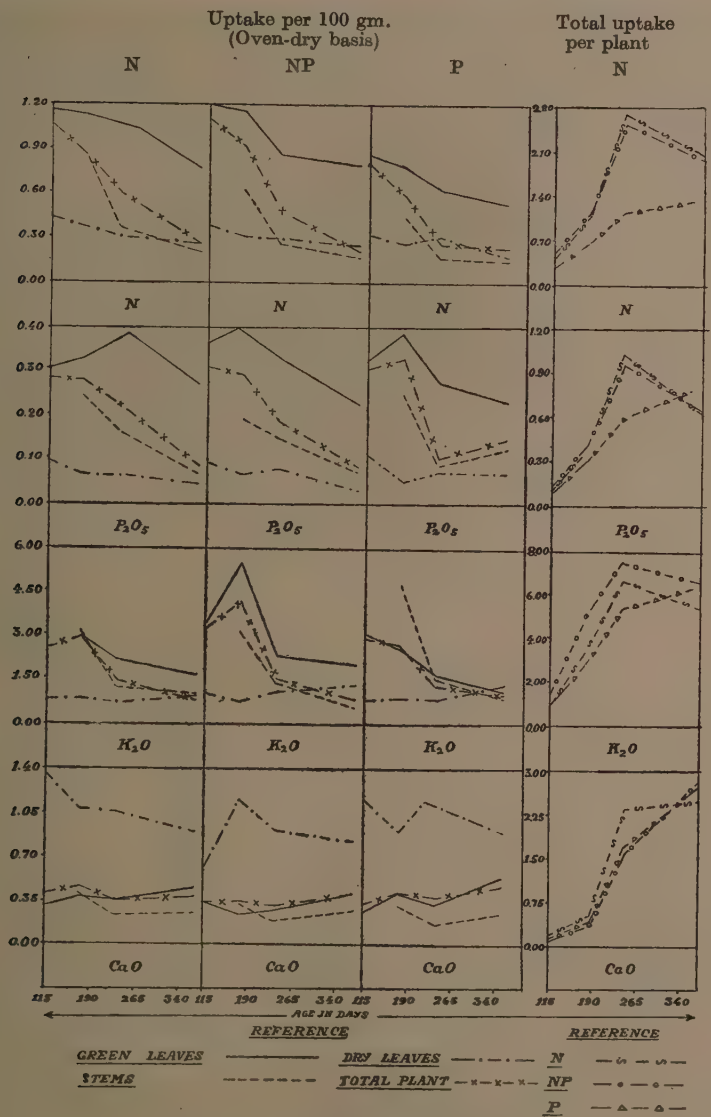


FIG. 3. Variety POJ 2878, 1938-39

For the proper evaluation of the effect of different treatments, the curves for the total uptake per plant and also per acre would be the best guide. In this case the percentage figures will be, in fact, misleading as the total uptake is circumscribed by the actual weight or the number of canes. Although the plant may show poor growth, the percentage figures may be either equal or in some cases even higher than in the case of vigorous plant. This is very well

illustrated in the case of treatment P in which although the figures for percentage constituents are practically similar to those of other treatments the periodical uptake per plant and specially per acre has been less. One interesting feature of these curves is the continuation of uptake of all the constituents after October, when in the case of the other treatments, the curves show a definite fall. This is inexplicable on the basis of the present knowledge and requires further investigation.

As regards the other treatments, NP shows an acceleration of uptake of all the constituents during theea rly stages. In the case of phosphate, this, however, continued throughout the life-cycle of the crop during the first season only, but was not visible during the following one. The high figures for potash in this treatment during both the seasons reveal that phosphate exerts a great influence on the uptake of potash. Russell [1937] has also stated that in the leaves of crops of vines and tomatoes, the percentage of $K_2O$ in the dry matter rises when phosphate is supplied. The comparison of all the curves for the two seasons given in Figs. 1 and 2 shows the higher uptake during the second season whether considered on percentage basis or per plant. As, however, the differences in the plant population per acre between the two years are rather wide, it would not be possible to definitely ascribe the increased

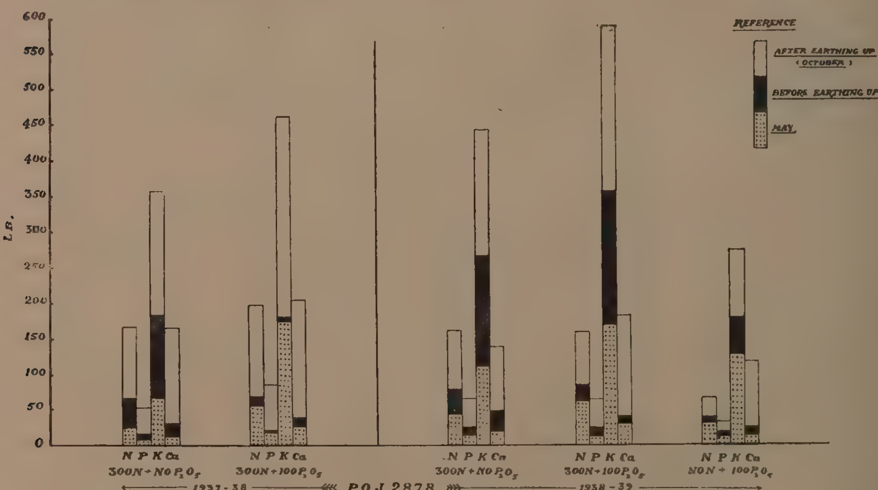


FIG. 4. Periodical and total uptake of N, P, K & Ca per acre

weight per plant as well as the increased uptake during the second season either to the climatic variation or to the residual effect on superphosphate applied to the previous crop of sugarcane.

Fig. 4 represents the total as well as periodical uptake per acre. All the pillars represent maximum uptake, i.e. till October in most cases. It would be seen that the maximum uptake per acre is of potash followed by that of nitrogen while in the case of phosphate it is the least. As regards the treatments, NP has shown higher uptake during the season of 1937-38 which is

chiefly due to the higher yield per acre in this treatment. This effect is not observed during the next season except in the case of potash. In the case of treatment P, the total uptake is much less than in the other treatments. As regards the periodical uptake, it is found to be negligible during the first four months till mid-May. It is only after this period that the rapid absorption of all the constituents starts, more than 50 per cent of the total absorption being observed from July onwards till October after which there is a fall.

In the case of series II, the analysis for mineral constituents were done from October onwards and the figures for the whole plant are given in Table XII.

TABLE XII

*Mineral constituents per plant (gm.)*

| | October | | | | Harvest | | | |
|---|---|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | CaO | N | $P_2O_5$ | $K_2O$ | CaO |
| 1937-38 | | | | | | | | |
| NP—450 N+100 $P_2O_5$ . . . | 2·82 | 0·78 | 5·24 | 1·44 | 2·12 | 0·92 | 4·96 | 2·30 |
| $N_2$P—450 N + 150 $P_2O_5$ . . . | 3·02 | 0·77 | 6·59 | 1·65 | 2·14 | 1·11 | 4·25 | 2·19 |
| NP—600 N + 100 $P_2O_5$ . . . | 2·32 | 0·66 | 5·22 | 1·41 | 3·12 | 0·82 | 5·14 | 2·60 |
| $N_2$P—600 N + 150 $P_2O_5$ . . | 3·33 | 0·74 | 6·00 | 1·63 | 3·00 | 0·75 | 5·54 | 2·42 |
| 1938-39 | | | | | | | | |
| NP—450 N + 100 $P_2O_5$ . . . | 3·70 | 1·25 | 7·90 | 1·88 | 1·96 | 0·73 | 4·82 | 2·92 |
| $N_2$P—450 N + 150 $P_2O_5$ . . . | 4·06 | 1·53 | 8·48 | 1·91 | 2·32 | 0·85 | 4·17 | 3·35 |

It would be seen that with the additional dose of 50 lb. $P_2O_5$ at earthing, the maximum uptake of all the constituents except that of $P_2O_5$ is increased during both the seasons. In the case of $P_2O_5$ this increase is not so very evident during the first season. This higher uptake of nitrogen appeared to be the cause of delay in flowering in this treatment in both the seasons, it being quite evident during the first season. There has been, however, no advantage from the standpoint of weight per cane. The differences in maturity are not also of outstanding merit. It seems, therefore, that while this additional dose of 50 lb. $P_2O_5$ is useful in accelerating the uptake of other mineral constituents specially of nitrogen and potash, this increased uptake of these nutrients has been of no advantage from the standpoint of crop growth mainly due to unfavourable climatic conditions which set in by this time.

*Mineral ratios.* The calculation of mineral ratios as $N/P_2O_5$, $N/K_2O$, etc. for both green leaves do not show any variation of magnitude between the two treatments of N and NP. These data are not, therefore, reported. Between the two seasons, however, the ratio is much narrower in the case of $N/P_2O_5$ as a result of higher uptake of $P_2O_5$ during the latter season—the maximum figure being 3·7 in October during 1938-39 as against 5·0 for the former one. No differentiation in growth is, however, observed between these seasons which could be attributed to the variation in these ratios. It, therefore, seems that sugarcane can stand wide fluctuations in the mineral constituents without any detrimental effect on the development of the plant. The

agrobiologic ratio of the three important elements of NPK differs also considerably from the one of Mitscherlich specially in potash, the ratio being 3:1:9 as against his 5:1:2. This may be due to the high potash content of the soil under investigation.

*Nitrogen fractionations in green leaves.* During the season of 1937-38 detailed analysis of nitrogen fractionations were carried out for the green leaves (Table XIII). As the ammoniacal nitrogen was determined by distillation the figures for the same would contain some amide N as well and as a result the reporting of separate figures for these is not followed. The only outstanding feature is the least amount of protein nitrogen during September which seems to be due to the rapid uptake of inorganic mineral nutrients during this period. By October much of this has been converted into protein nitrogen, the percentage of protein nitrogen being higher in NP treatment than in nitrogen alone. In the case of series II these nitrogenous fractions were determined in October samples only. Owing to higher nitrogenous manuring, protein nitrogen is much lower in this series than in the first one. There has been, however, not much variation in these constituents due to the additional dose of $P_2O_5$ at earthing. As the figures for other fractionations did not show any variation between the treatments, only protein and crystalloid nitrogen were determined during the second season. These data, however, do not show any differences of sufficient magnitude between the treatments and as such they are not reported.

TABLE XIII

*Nitrogen fractions in green leaves*

1937-38

| Treatments | Series I | | | | | | Series II | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 300 lb. N | | | | | | 450 lb. N | | 600 lb. N | |
| | June | | September | | October | | October | | October | |
| | N | NP | N | NP | N | NP | NP | $N_2P$ | NP | $N_2P$ |
| Ammoniacal and amide nitrogen | 4·05 | 3·78 | 3·06 | 3·99 | 4·75 | 5·73 | 3·30 | 4·80 | 5·30 | 6·80 |
| Nitrate nitrogen . . | 1·62 | 1·35 | 2·60 | 2·60 | 0·88 | 1·40 | 1·04 | 1·20 | 0·99 | 0·88 |
| Crystalloid nitrogen . | 21·14 | 19·97 | 27·10 | 25·60 | 15·60 | 6·20 | 25·80 | 32·24 | 37·20 | 32·20 |
| Protein nitrogen . . | 16·24 | 11·63 | 1·60 | 5·60 | 23·20 | 22·20 | 11·00 | 7·46 | 6·30 | 7·50 |
| Protein nitrogen per cent of total nitrogen | 43·40 | 36·80 | 5·60 | 17·90 | 59·90 | 78·40 | 29·90 | 18·80 | 14·50 | 18·90 |

## GENERAL DISCUSSION AND CONCLUSIONS

The reaction of the different phases of plant life to the basal phosphatic manuring is found to vary according to the initial phosphatic status of the soil. During the first season, phosphatic manuring has definitely led to (1) rapid increase in tillering resulting in large number of canes per acre and (2) acceleration of growth at early stages with early senescence which brought

about early flowering and early maturity. It also maintained the water content of the leaf at a higher level at the early stage of development which is of great practical significance, as from the standpoint of climate this is the period of highest water requirement. Phosphate further made the leaves broader but thinner and pale green and the rate of photosynthesis was higher during the early stages.

During the following season no distinct favourable effect of phosphatic manuring was evident, the treatments N and NP showing practically similar behaviour during the various phases of plant life. This experimental work was conducted in the block which had received application of superphosphate and oil-cakes to the previous crop of sugarcane in the three years' rotation and the residual effect of this phosphate seems to have continued even on the next crop of sugarcane. The analyses of the soil samples collected at the time of planting have shown that while the figures of available phosphate were practically similar during both the seasons, being respectively 25·1 and 25·9 mg. per 100 gm. of soil, there had been a definite rise in the level of total phosphates during the second season, the figure being 53·7 mg. for the first season as against 66·4 mg. for the following one. The response of the crop to the phosphatic manuring during the first season and non-response to it in the following one thus reveal the possible initial levels of soil phosphate at which deficiency and sufficiency of phosphate are envisaged.

Trials in outside centres by the provincial department of agriculture and sugar factory management have shown that in soils newly brought under sugarcane cultivation there was a response to phosphatic manuring in many cases, while in others on which sugarcane cultivation was going on for a number of years, no response was observed. This appears to be mainly due to the accumulation of phosphates in the soil from oil-cakes which are used as nitrogenous top-dressings to these crops. Further in certain cases even a deleterious effect of phosphatic manuring was revealed as could be judged either by yield or maturity of cane. The analyses of soil samples in these cases have shown the figure of total phosphate to be above 111 mg. per 100 gm. of soil. Russell [1937] has also reported reduction in crop yield as a result of excess of phosphate. While it will be no doubt presumptuous to draw any definite conclusions with such a small number of figures, they can form a useful basis for future investigations in the determination of the three levels of phosphates at which phosphatic manuring will be (1) beneficial, (2) ineffective and (3) deleterious.

In the case of available phosphate, the similarity of figures of both the seasons suggests a lack of relationship which would be quite intelligible when one would consider the periodical rate of uptake of this constituent by the crop. It has been shown that about 70 per cent of the phosphatic requirement of sugarcane is absorbed during the stage of the grand period of growth which in the case of January-planted cane starts five months after planting. It would be thus reasonable to imagine that owing to the maintenance of proper moisture for bacterial action as a result of short-period irrigation and evolution of $CO_2$ by roots, there would be an increase in the availability of soil phosphate as compared to the figure given above for the samples collected at the time of planting. This has been, in fact, confirmed by the periodical

analyses of exudates from mid-May onwards in later experiments which definitely revealed increasing availability of phosphate and potash with the progress of time. Some workers have found a correlation between the available soil phosphate and response to phosphate manuring. Kerr and Stieglitz [1938] have, however, shown that in order to secure this concordance it would be necessary to consider the nature and the amount of available soil plant food reserves as an important function of the stage in the crop sequence at which the soil is to be sampled. In other words, this concordance can be definitely secured if the soil is sampled at the time of the maximum availability of phosphate. This would be rather a difficult point to determine. Besides, as sugarcane is a long-period crop and as the real uptake starts after about five months of growth, even total soil phosphates are expected to give as good a concordance for this crop as the available one. In order to judge the relative value of both available and total soil phosphates for this purpose, it is, therefore, felt necessary to determine the levels of both available and total soil phosphates for different soil types at which phosphatic manuring will be either good, ineffective or deleterious.

From the standpoint of the biochemical activities of the plant also, the initial phosphatic status of the soil is found to be important. During the first season, phosphatic manuring has not only brought about an acceleration of the uptake of all the constituents (N, P, K and Ca) during early stages, but the total uptake was maintained at a higher level throughout in the case of P and K and was only equalled for the other constituents by the treatment of N alone at harvest time. In the following season, however, there was no difference either in the rate of uptake or the total one in both the treatments of N and NP except in the case of potash whose uptake was definitely higher in the NP treatment ; but when one compares seasons, the higher level of uptake of all these constituents during the second season in both these treatments is clearly revealed. Owing to wide differences in plant population per acre during the latter seasons, it is rather difficult to attribute this higher uptake per plant to the higher level of soil phosphate. Some indication of the advantage of higher level of soil phosphate can be obtained from the mineral ratios which in the case of N/P has been greatly narrowed during the latter year. It clearly proves the greater availability of phosphate with its higher uptake during the latter year and although the nitrogen uptake is also high during this year as compared to the previous one, it has not shown proportionate increase which has been the reason of the low ratio of N/P obtained during this year. From the standpoint of the life processes of the plant, however, no distinct advantage has been observed of this low ratio and it appears that sugarcane plant can stand without any detriment wide fluctuations in mineral ratios.

In the case of heavy nitrogenous manuring, 450 lb. N and above, a second dose of 50 lb. $P_2O_5$ which was applied at the time of earthing with a view to secure early maturity of cane was found to be ineffective. On the other hand, studies in the mineral uptake have shown greater uptake of nitrogen in this treatment as against the other one which did not receive this additional dose of $P_2O_5$. No advantage of this higher uptake has been observed, such as for instance, an increase in growth or tonnage and this accumulation of nitrogen

can, therefore, be attributed to luxury consumption. It appears that the plant absorbed this nitrogen at a time when the climatic conditions were becoming unfavourable for growth (October) and as a result the absorbed nitrogen could not be utilized. Perhaps in early plantings this higher absorption of nitrogen due to phosphatic manuring may be much earlier when the climatic conditions would be suitable for growth and as such may be useful for securing higher cane tonnages without at the same time producing detrimental effect on sucrose formation and experimental work on this line is in progress.

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## *ERRATA*

*The Indian Journal of Agricultural Science*

*Vol. XII, Part IV, August 1942*

Plate XXI—The Correct letterpress is as follows :—

1. Light sienna 2. Sienna 3. Light red 4. Red 5. Light brown 6. Brownish sienna 7. Brown 8. Reddish brown

Page 530, line 4, *for* ' Densily ' *read* ' Densely '

Page 534, line 25, *for* ' govineing ' *read* ' governing '

Page 552, column 2, first row, *for* ' Shoit ' *read* ' Short '

Page 554, column 2, *for* ' $W^1$' etc. *read* ' $W_1$ ' etc.

Page 559, column 3, line 1, *for* ' 9 : 3 : 4 : 1 ' *read* ' 9 : 3 : 3 : 1 '

*Vol. XII, Part VI, December 1942*

Page 895, line 7, *for* ' $K^1{}_2 \frac{{}^2c}{1-\propto}$ ' *read* ' $K^1{}_2 \frac{\propto^2 c}{1-\propto}$ '

Page 905, line 7, *for* ' $R_2{}^{AS}$ ' *read* ' $R^2$ OS '



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(February 1943)

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